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BRL

REPORT NO. 542
April 1942

SOME COMMENTS ON THE FORM OF THE DRAG COEFFICIENT AT SUPERSONIC VELOCITY

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[redacted]

BALLISTIC RESEARCH LABORATORY
REPORT NO. 542

Ordnance Research and Development Center Project No. 4007

Thomas/emh
Aberdeen Proving Ground, Md.
20 April 1945

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Abstract

A form of representation of the drag curve at supersonic velocity is suggested. Only two unknown constants are required for each shell, hence firings at two velocities fix the function. For the case of a conical head and square base, the problem can be reduced to one constant. Good experimental confirmation is found.

[redacted]

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The paper is concerned with presenting several comments on the state of knowledge of the general form of the Mach number, drag coefficient relation. In particular the discussion centers about an empirical parameter which has been found extremely useful for interpreting retardation data and for extrapolating beyond the range covered by experiments to date. Unfortunately, exterior ballistics is still quite in the stage of relying on empirically determined parameters; consequently it is highly desirable to obtain as much information as to the underlying physical picture as possible from each parameter which seems to "work" in allowing a wide range of interpolation or extrapolation to be based upon several measures of its value. One such parameter seems to be what the author has called the Q factor, where $Q = \sqrt{1 + K_D M^2}$ with M the Mach number and K_D defined by the force equation:

$$F = - K_D \rho d^2 v^2$$

where ρ, d, v, F are air density, body diameter, velocity, and air resistance respectively. The significance of Q is that for a great many projectile shapes the Q curve is virtually linear in M above a certain Mach number, thereby reducing the drag function to a function of just two parameters and thus greatly simplifying its determination. Further, in the case of a square based conical headed shell it is possible to predict the slope of the Q, M relation, reducing the drag function to one unknown parameter.

A. General Discussion of the Drag Function at Supersonic Velocity

Basically there are three groups of people interested in the form of a drag function; the theoretician, experimental ballistician, and the firing table computer. All have the same immediate end, ascertaining the action of the air upon a body moving through it, but quite different ulterior motives.

1. The firing table computer has an objective which is the most immediately obvious, an engineering problem to hit a given target. For this he can of course proceed purely empirically, firing every range, powder charge, and elevation. Such a procedure is tedious, so he turns to mathematical experiment and computes a trajectory. For this, data on the velocity dependence of the drag is necessary. The history of the attempts to formulate the problem theoretically is well known; also the final necessity to turn to empirical determination of the drag.* The last effort along the analytic representation was that using the Mayevski proposal of representing the drag as proportional to a power of the velocity with power and proportionality factor holding only over limited velocity zones; the exponent decreasing as the velocity increased. While this representation is not now in use,

* Cf. Cranz-Ballistik, Vl or Hayes, Elements of Ordnance, Chap. X.

[redacted]

recently it has been noted* that K_D for some bullets is well represented by $M^{-1/2}$ in some supersonic regions, the so-called "3/2" law. This gives, of course, an asymptotic value of 0 for K_D as $M \to \infty$. So long as the computer can work with accurate data pertaining to his particular shell, and in the region covered by the data, he is reasonably safe. Unfortunately, however, the relation between data and working region often becomes confused, and ignorance as to the physical nature of the drag curve becomes embarrassing.

a. Sometimes the accuracy of the data is such as to leave considerable doubt as to the form of the curve; a good example is the determination of J_4. Fig. 1 shows two curves with data obtained from the same shell, determined several years apart.

b. Sometimes the wrong shell is used in the experimental work. Fixing the drag curve then becomes very difficult. Fig. 2 shows the experimental points which were used to determine J_5**. The early points were for the correct shell, and seemed to lie below the overlapping points for the second shell, and so apparently the curve was made to pass below the experimental points. Thus while J_5 is a perfectly well-defined drag function, the shell which it represents is open to conjecture. Such a point is necessary to realize when considering the drag function form.

c. Occasionally it is requested that firing tables be extended to muzzle velocities higher than those covered by existing functions and without benefit of further firings. Since this requires extrapolation of the drag function, considerable difficulty is experienced. Such a revision of several of the standard drag functions is now underway in the computing branch. Considerable difficulty was found in working with such functions as J_5, where the function never did go through any experimental points; the author suggested the linearity of the ζ function as providing both an asymptotic value for K_D and a rough form; it is understood that this is being at least partially used.

* By L.E.C. [illegible] in England, by R. N. [illegible] of the [illegible], and by Major T. E. Sterne of the BRL.

** [illegible] firings, it was [illegible] possible [illegible] with the [illegible] shell and [illegible] a [illegible] similar shell [illegible] higher velocity. Cf. [illegible] Fig. 2. With the shells so nearly alike, the violent departure of curve from experimental points [illegible].

[redacted]

2. The theoretician has been concerned with the problem of air resistance for a long time as being one of the "basic" problems presenting itself whenever motion in a non-vacuum is considered. It is not proposed to discuss fully the theoretical aspects of the problem here; an excellent historical summary is given in Durand-Aerodynamic Theory. Vol. 1; the mathematical aspects are given in Karman- Problem of resistance in compressible fluids, Proceedings of V Volta Congress, Rome 1936; and a good, direct summary from the point of view of the ballistician is given by Birkhoff in BRL Report 422. The last seems to the author a bit pessimistic in some spots concerning the possibility of predicting drag; and slightly misleading in others such as the section in which it is stated that a good physical reason for the decrease of drag coefficient with velocity at supersonic velocity has never been given, but is on the whole a good summary. That which is of note so far as the theoretical work goes is the predictions as to the form of the drag function from the small bit of theoretical work existing. Basically, this consists of two parts only; the work from the so-called linearized theory where the influence of the shock wave is neglected and hence can hold only for projectiles of very acute ogive and for moderate velocity; and the flow past an infinite cone where a shock is assumed at the outset and a compatible solution for the flow between it and the shell surface found. The first was developed by Karman and Moore and the last by Taylor and Maccoll; although some modifications have been made to each.* Both of these give a decreasing function of K_D vs M; the latter exact solution having an asymptotic value for the high velocity end; the former approximate solution gives a somewhat higher rate of decrease of K_D with M, tending to a zero value. While the conical solution does not give an analytic solution for the K_D,M relation; an approximate representation of the shock angle which works very well above $M \geq 2$ and cone angles $> 10°$ is

$$\sin^2 \theta_W = \frac{\gamma+1}{2} \sin^2\theta_s + \frac{1}{M^2}$$

where θ_W, θ_S are shock and cone semi-angle respectively. The drag coefficient is very nearly proportional to the product $\varphi \sin^2\theta_W$ where φ gives the pressure rise from shock to shell surface. φ first rises with M then falls to a constant value of

$$\left(\frac{2}{1+\frac{4\gamma}{(\gamma+1)}}\right)^{\frac{\gamma}{\gamma-1}} = 1.05 \quad \text{for air with } \gamma = 1.405$$

* Ferrari, Atti. R. Acc. Inst. Turin, [illegible]
Busemann- Luft fahrt forschung 19[illegible]
Thomas, BRL 483
Karish & Critchfield NDRC Armor and Ordnance Report A-2[illegible].

The contribution of skin friction to the form of the drag curve is largely unknown; existing knowledge comes from a few estimates from spin deceleration measures and on values carried over from subsonic experiment at equivalent Reynolds numbers. An analysis has been made by Cope* indicating that for the laminar case incompressible fluid theory furnishes a fair first approximation, while the turbulent coefficient requires consideration of compressibility effects.

Conditions at the base are even less well known. Methods for computing the flow around the corner of base and boat-tail have been given by Ferrari** Unfortunately the models fired to date at the BRL where the drag and physical measurements have been known well enough to carry out the calculation have the complication of a fairly large rotating band which makes unknown the value of the velocity before the boat-tail. One remark, however, is pertinent; the too frequently made assumption that base and head drag are independent can possibly lead to quite erroneous conclusions when one states that base is independent of head rather than head of base. The fact seems quite obvious when one considers that the pressure change in the expansion around the body-shoulder and again at the boat-tail depend on the velocity at the ogive surface; the error seems nonetheless a not uncommon one in the discussion of shell design and performance. In general, then, the cone case can serve as a guide to the general form of drag function, giving an asymptotic value of K_D greater than zero; aside from this the theory is yet to be developed.

3. The experimental ballistician is concerned with the form of the drag function from two standpoints; one in the determination of the drag curve for the computer; and the other in regard to shell design where a comparison of two shells is desired.

Modern determinations of the drag coefficient, K_D, consist essentially of firing over a short base line; along which are placed several (something greater than three) timing stations of one kind or another. The drag function is built up by firing a number of rounds at various muzzle velocities; each round fixing one point on the drag curve. Over this short base line, the trajectory can be kept quite flat; and if the launching conditions could be made perfect, one could forget the angular motion of the projectile and confine himself to the translatory portion. In such a case the zero point drag function, i.e. without yaw, becomes easily determinate from the firings, and the effect of yaw can then be determined at any or all desired portions of the curve by disturbing the launching conditions. In practice, however, only very rarely are conditions such that rounds having zero yaw are fired; particularly is this true in the firings carried out in the aerodynamics range where the accuracy in drag measures is well within the one per cent mark, so that yaws which would be inappreciable in effect under more crude measuring conditions, here show up markedly. So one is faced with the problem of determining both the effect of yaw and the zero point curve from which this effect is to be measured. The general procedure has been to fire a number of rounds at as nearly the same velocity as possible, correct the drag to put all rounds at the exact same velocity, and then determine the yaw drag correction and the zero point value.

* BARC 43/14, 43/[illegible]

** Ferrari-Aeronautica 16 [illegible]

implies K_D is an inverse quadratic in M. In view of the previous discussion on the form of the curve to be expected from what theory there was such a variance is quite reasonable. The only restriction introduced by using the Q fit is that the number of free parameters is reduced from three to two. Just for this reason it is especially useful for small velocity corrections, when the drag has been measured at only two or three points. For more generality, the quadratic fit to K_D itself may, of course, be substituted. One point should be noted, and that is the obvious fact that this factor tends of itself to smooth any dispersion in K_D at the low velocity end. Roughly, a small change in K_D is about halved in the quantity Q-1 in this region. On the other hand, however, the situation is reversed and Q magnifies the error in the high velocity end. (Since the accuracy of measure is likely to be somewhat better at the lower velocity end, this effect is opposite to that which would be desired so far as smoothing parameter is concerned).

This representation was then applied to a number of resistance functions for which the experimental points were known. The representation was quite good; so the method was adopted tentatively in the analysis of the firings carried out in the aerodynamics range. So far the results have been very satisfactory. The process consists simply in taking several points of the smallest yaw obtainable, and determining the Q, M relation over the region covered. The points are then corrected along the line to a common velocity, and the yaw-drag effect then removed. A fit of the zero-points thus determined for the total number of velocity groups can be used to correct the local Q curves, or the overall curve if such was first determined. It has been found, however, that the first velocity correction was sufficient, provided it was not made over too extended a velocity range (say, less than 100 ft/sec.).

A. Q Factor - Representation.

1. In figs. 7 - 1[illegible] are given a comparison of representations in the supersonic range of K_D and Q vs M. The data given is of two kinds: First, the basic data from which the so-called standard resistance functions were determined. Second, the Q values for the same data; with the exceptions of J7 and J8, the data was obtained at Aberdeen.

J7 and J8 are from British firings. The scatter in the [illegible] functions reflects simply the apparatus in use at that time (1920-36). The data for the British shell without boat-tail is quite consistent; the other shows considerable scatter which was not explained in the report describing the firings. The chief point of interest is obviously the fact that the representation is at least as good as the data; and the advantage over the K_D representation is that the general form of the curve is somewhat better determined and allows some confidence in an extrapolation.

[redacted]

It is worthwhile to consider the J8 function in somewhat greater detail. The results upon which this function is based are described in BARC 43/01; and the function was intended by them to serve as a standard resistance law for a modern streamlined projectile having a square base and ogival head. For this purpose considerable effort was made to represent the experimental points by an empirical, analytic expression. For the region above the velocity of sound, i.e. $M > 1.0$ and supposedly holding to $M < 4.46$, the expression given is:

$$\begin{aligned} f_R(M) = {} & 2.136877400\, M^{-50} - 6.829298000\, M^{-45} + 7.644594000\, M^{-40} \\ & - 3.470684000\, M^{-35} + 0.422137000\, M^{-30} + 1.071340000 \\ & - 0.374350000\, M + 0.051250000\, M^2 - 0.000090000\, M^5 \\ & + 2.160000000 . 10^{-12}\, M^{16} - 1.500000000 . 10^{-28}\, M^{40} + 2.000000000 . 10^{-56}\, M^{80} \end{aligned}$$

where this formula was made to have second order contact at $M = 1.0$ with a corresponding one for the subsonic case; and the large number of figures are carried for this reason. In setting up the expression, the slope $\frac{df_R}{dM}$ was made zero at $M = 4.46$. (f_R is based on the radius rather than the diameter as in K_D, hence $f_R = 4K_D$.) This formula is undoubtedly very useful in representing the experimental data, and for computing purposes, but does not give much of a tangible idea as to the physical form of the drag coefficient. As an interesting comparison, the results using the Q fit and this representation are compared in Figs. 16 and 17. for the region above $M = 1.4$, the point below which the Q representation starts to curve. For simplicity the results are presented in the two graphs, the experimental points being present on each. The British curve was lifted bodily from BARC 43/01, it being quite laborious to replot the curve from the expression given above. For the same reason no residuals are computed for the fit of the data by the curve. For the Q representation, however, the standard deviation of a single observation is .003 in K_D. In view of the apparent scatter of the points, the representation does not seem to be too bad. As the Mach number decreases, so also of course does the accuracy of the representation, for the actual K_D curve bends off while the Q representation gives in general a continued rise. The British experimental points and those used in the present calculations will be seen to differ slightly. No tabulation of these points was available to the author, so they were read from a small scale graph on which J8 was plotted, some error being introduced in the process. This graph was not that in BARC 43/01 and apparently several mean points have been used in this latter. In general, however, the comparison should be good for illustrating the Q factor.

The results of the Q representation of the standard drag coefficient functions are given in table I, from the relation $Q = a + bM$ the a and b values are listed. For the functions J_2 and J5, where two types of projectiles were used, both types are given together with the standard deviation in b; the results using both types together is also given. It is seen that to the significance of the data, there is no difference between the shells for J2; but an appreciable difference for J5 in spite of the very low accuracy of the results. As remarked in the footnote on page 3, the close resemblance between the two shells makes so large a difference curious; but since there was only a limited velocity range covered by firings of both types, and the dispersion so high, not much can be gained by speculation.

2. To show a typical case using data obtained with more accurate modern equipment the results from a recent program fired in the aerodynamics range are given. The shell was a model of a proposed 90-75mm sabot type shell. The case is somewhat unusual in some respects but clearly illustrates the use and accuracy of the Q factor for a shell of simple shape. This design has a pointed conical head, half-angle = 12°1; and a cylindrical afterbody in two lengths. Cf. Figure 19. . The shell had a high stability factor, ~3.5; consequently an unusually high number of rounds with negligible yaw (<1° maximum yaw) were obtained. Combined with the circumstances that while the firings covered the range $M = 2 \rightarrow M = 3$ very few rounds had velocities nearly the same, a somewhat different reduction procedure was used. The rounds of zero yaw were used to fix the zero curve, computed by use of the Q factor; and the yaw effect then computed by assuming that $K_{D_{\delta^2}}$ was independent of velocity. Apparently the supposition was justified for the results show very little dispersion. These are given in Table 2 and Fig. 18. The first of these, 2a, gives M, Q, K_D for the zero yaw case; subscripts O and c denote observed and computed. The latter results from computing back from the constants of the Q straight line fit of Q, M by least squares to the O points. The second 2b gives the data for the shells with yaw. Three things should be noted.

(1) The K_D values computed on the basis of rotating band rather than body diameter seemed to fit the observations better, and so were used.

(2) The Q, M curve determined from the short body shell alone seemed to work equally well on the longer body, so all points were used in the final solution. (For comments on the program, whose main result was the effect of body length on various of the aerodynamic coefficients, see BRL).

(3) For the yaw representation, the quantity $\frac{\Delta K_D}{K_D} \, \frac{1}{\bar{\ell}}$ was plotted versus $\bar{\delta}^2$ where ΔK_D is the difference between observed and computed K_D; and $\bar{\ell}$ is the length of the shell divided by the length of the shorter shell and is intended to take into account

the greater projected area of the longer shell for a non-zero yaw. The representation will be seen to be extremely good; the largest K_D residual is seen to be .002 for both zero and non-zero yaw case corrected for yaw. This amounts to about .0011 standard deviation in K_D, or slightly less than 1%.

3. As has been mentioned the great recommendation of the Q factor from the physical point of view lies in its prediction of an asymptotic, non-zero, positive value for K_D; thereby agreeing with the little theory extant. The implication should not be taken, that there should come a point at which the asymptotic K_D is reached; on the contrary it is quite obvious that additional interaction between body and fluid takes place when the velocities approach, say, those of meteors. Neglect of variance of γ, of the effect of heat conduction, etc. all must enter at velocities which are high in the ballistic case but reasonably low relative to meteoric velocities. In the supersonic range of ballistic concern, however, Q should furnish a very convenient guide for use in comparing projectiles. In fact, at the risk of further muddling the already quite confused picture of ballistic terminology, it might be suggested that the term "form factor" in its present use where it refers to the ratio of two drag functions and usually amounts to nothing more than an empirical fix factor which varies with velocity, be replaced by the slope and intercept of the Q, M relation as giving more physically meanful parameters. From the foregoing discussion and results it would in general appear possible to completely describe the drag coefficient by firing at two velocities. Furthermore, since the flow past a cone can be computed theoretically, and one would expect the head pressure to be the chief factor ultimately, comparison of calculation with firings of a projectile with conical head should be highly interesting; for assuming the theory is capable of predicting the asymptotic drag there remains only the one unknown parameter.

For this computation data is had for cylindrical based projectiles having conical heads of 10°, 20°, 30°, semi-vertex angle as reported by the British in BARC 43/13, and data concerning 12°1 and 9°53 cones from the aerodynamics range at the BRL. No descriptions of the British projectiles were available other than that they were 40mm caliber. Drawings of the BRL shells are given in Fig. 19. As stated, the results for the 12°1 cone already discussed were based on the band diameter. Those for the 9°53 cone were, however, based on the body and in the absence of specific information it is expected so also were the British results. So several of the 12°1 projectiles having the same body diameter were used to determine a Q, M relation based on body diameter. For the computations only those points were used for which the flow behind the shock wave is everywhere supersonic. For the 10°, 9°5, 12°1 cases this is no restriction since this is true for M $\gtrsim$ 1.2; for the 20° and 30° cases the points are M $\gtrsim$ 1.3 and 1.6 respectively. The results are listed below as ${}_LK_{D_c}$ and ${}_LK_{D_o}$ where these refer to calculated from the expression*

*BRL Report No. 483.

[redacted]

$$K_{D_{limiting}} = \frac{\pi}{4}\left(\frac{2}{1 + \frac{4\gamma}{\gamma+1}}\right)^{\frac{\gamma}{\gamma-1}} \times \sin^2\theta_s = .8254 \sin^2\theta_s$$

for air, $\gamma = 1.405$

and observed as determined from b^2 in the $Q = a + bM$ relation.

Cone θ_s	${}_LK_{D_c}$	${}_LK_{D_o}$	${}_LK_{D_o}$ *
9.53	.0226	.0171	.0173
10	.0249	.0200	.0185
12.1	.0363	.0236	.0242
20	.0966	.0532	.0544
30	.2064	.1100	.1095

It will be observed that the two do not agree, the computed value being consistently larger than that observed. Plotting observed versus computed, however, shows a surprisingly exact linear relation between the two. Fitting this line by least squares in the form:

$$\alpha + \lambda\, {}_LK_{D_c} = {}_LK_{D_o}$$

one obtains

$$\alpha = .0060 \qquad \lambda = .5014$$

and representing obtains the column ${}_LK_D$ *. The linear fit thus seems very good. The result is quite interesting. The slope of the curve makes it appear as though a factor of two had been missed in the expression for ${}_LK_D$; checking however, shows no such error apparent. The non-zero value of α is somewhat easier to explain; to the author it seems that this must be the contribution of the rotating band, which would be expected to act in just such a way. So it would appear that the slope of the Q, M graph can be fairly accurately predicted for a conical head, blunt-based projectile by simply taking half the theoretical K_D limit and adding a slight correction for rotating band. This last would have to be determined for each variance of band relative to caliber; here the rounds used from the BRL had the same ratio, and apparently the British shells were not too dissimilar.

A guess might be made as to the λ value differing from unity. Tacitly the assumption was made that in the limit the base contribution fell out, i.e. vanished as something less than M^2. If, however, the value fell off directly as M^2, an additional term should enter. Some evidence that this is the case can be obtained by computing ${}_LK_{D_o}$ for a projectile similar to the 9°53 case except that it has a boat-tail. The value comes out to be ${}_LK_{D_o} = .0158$; which is lower yet than for the square based shell.

[redacted]

This points strongly at the already too painfully obvious fact that conditions at the base are too unknown, that not only numerical data but a physical understanding of the conditions there is one of the most pressing ballistic problems.

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[redacted]

TABLE I

Q Representation of Standard Drag Coefficients

$$1 + K_D M^2 = Q = \alpha + \lambda M$$

Type		α	λ	
J_2	5° boat-tail	.9575+.0077	.1263+.0039	
	7° boat-tail	.9536∓.0047	.1271∓.0027	M > 1.0
	both	.9548±.0044	.1271±.0024	
J_3		.8066	.2894	M > 1.0
J_4		.3624	.2207	M > 1.0
J_5	75mm Mk IV	.8780 +.0061	.1970+.0044	
	3.3" Mk.II	.8177∓.0139	.2424∓.0069	M > 1.0
	both	.8328±.0060	.2329±.0035	
J_6		.9460	.1464	M > 1.0
J_7		.9298±.0147	.1474±*.0057	M > 1.4
J_8		.9625±.0020	.1349±.0008	M > 1.4

* Since the J_7 and J_8 projectiles are the same except for a boat-tail on J_7, this is slightly startling. The same situation is reflected in the drag functions as used; the two cross at some point and thereafter J_8 is the lower. Physically this does not make much sense, and from the experimental points it would seem to be just a reflection of the great scatter at the high velocity end in J_7. This is seen by observing the relative accuracy in the determination of the constants a and b for J_7 and J_8.

[redacted]

TABLE 2a

12°1 Cone, Zero-Yaw

Rd.	M	Q_D	Q_c	K_{D_o}	K_{D_c}	
723	2.032	1.253	1.251	.138	.137	
724	2.219	1.281	1.279	.130	.129	
701	2.254	1.287	1.288	.126	.126	A-short
700	2.287	1.290	1.289	.127	.126	
705	2.490	1.316	1.318	.118	.119	
743	2.839	1.379	1.377	.108	.107	
704	2.205	1.274	1.277	.128	.130	B-long
707	2.783	1.361	1.362	.110	.110	

$Q = .9532(\pm.0037) + .1467(\pm.0015)M$

K_D based on rotating band diameter

[redacted]

[redacted]

TABLE 2b

Summary of Drag Data

(b) Rounds with yaw

Rd.	Type	M	$K_{D_{o\,band}}$	$K_{D_{c\,band}}$	$\overline{\delta^2}$	$\left[\frac{\Delta K_D}{K_{Dc}}\ \frac{1.8}{\ell}\right]_o$	$K_{D_{o\,band}}$	$\left[\frac{\Delta K_D}{K_{Dc}}\ \frac{1.8}{\ell}\right]_{c-1}$
712	A	2.264	.155	.127	23.0	.220	.125	
742	A	2.624	.118	.115	2.8	.026	.115	
709	A	2.689	.114	.113	0.7	.008	.113	
741	A	2.821	.111	.109	0.4	.018	.111	
740	A	2.866	.110	.108	1.0	.018	.109	
720	B	2.114	.137	.133	2.9	.028	.133	
722	B	2.134	.134	.132	1.2	.014	.132	
721	B	2.315	.133	.125	5.9	.059	.125	
703	B	2.371	.125	.123	1.5	.015	.123	
719	B	2.481	.128	.119	7.3	.069	.118	

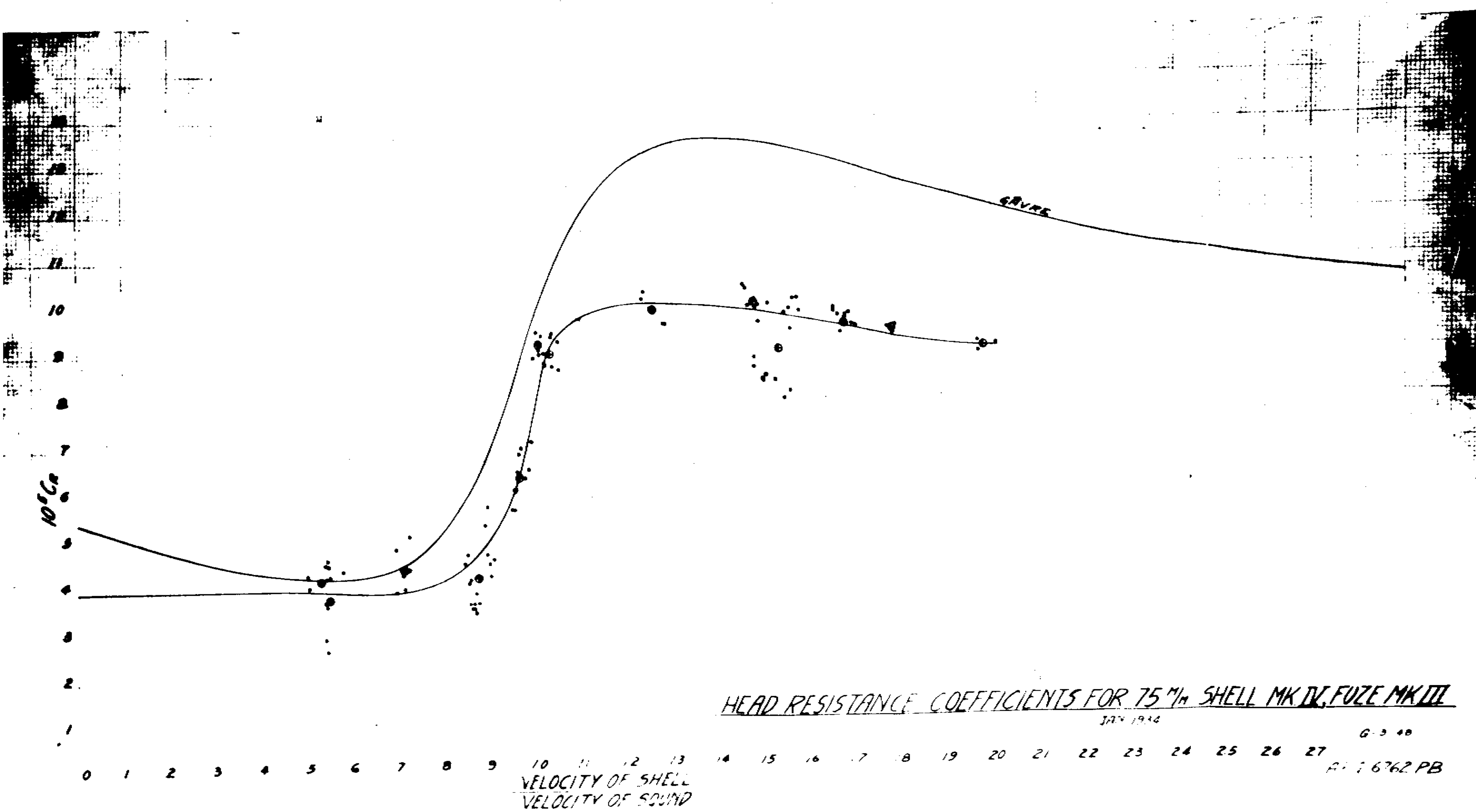
(1) Putting a straight line thru the origin and the above points:

$$\left[\frac{\Delta K_D}{K_D} \cdot \frac{1.8}{\ell}\right] = .0102(\pm.0004)\,\delta^2$$

(2) Putting a straight line thru the above points <u>and</u> the points of zero yaw with slope as well as intercept free:

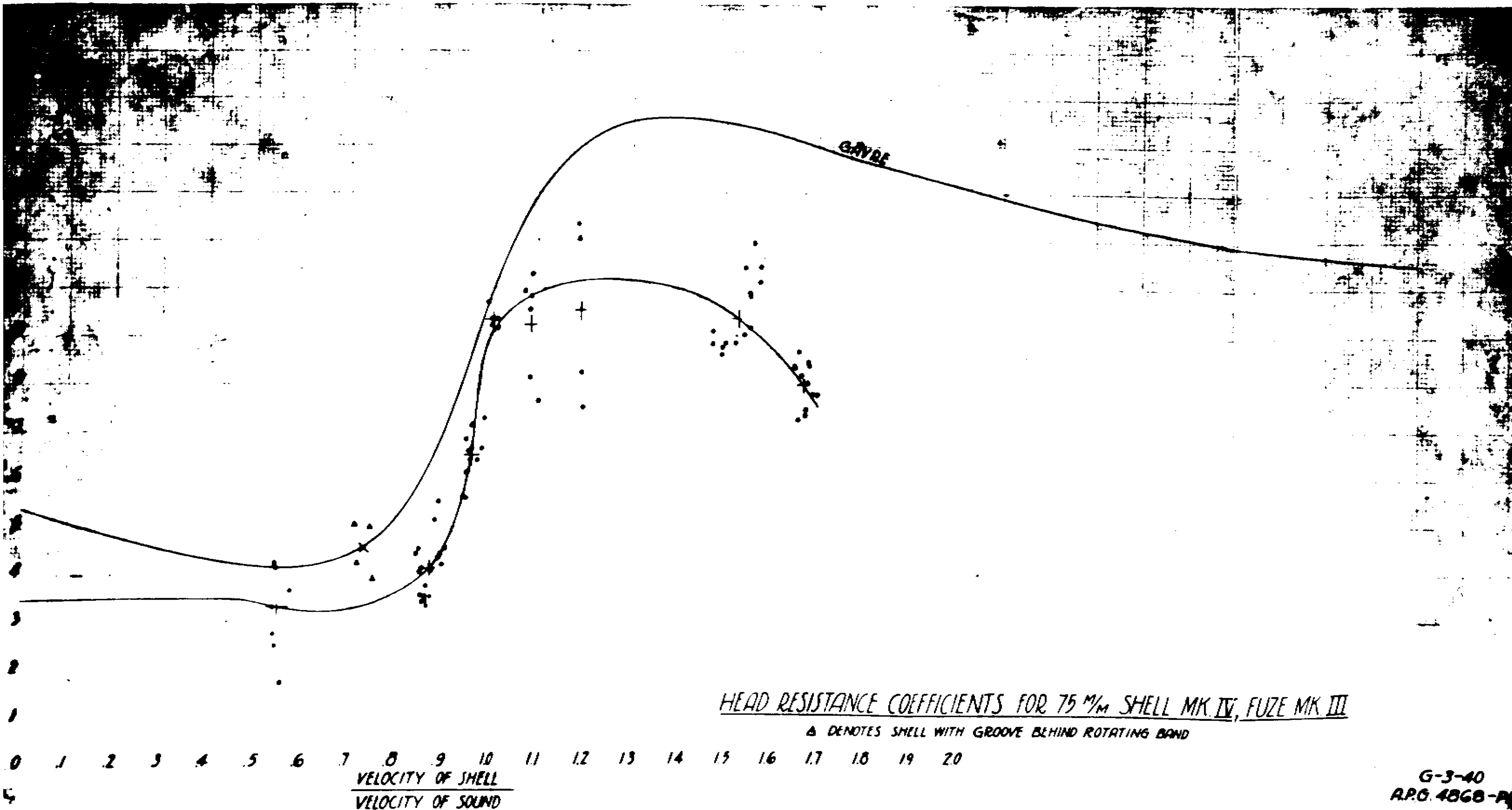
$$\left[\frac{\Delta K_D}{K_D} \cdot \frac{1.8}{\ell}\right] = \left[.0094 \pm .0003\right]\delta^2 + (.0024 \pm .0019)$$

[redacted]



HEAD RESISTANCE COEFFICIENTS FOR 75 M/M SHELL MK IV, FUZE MK III

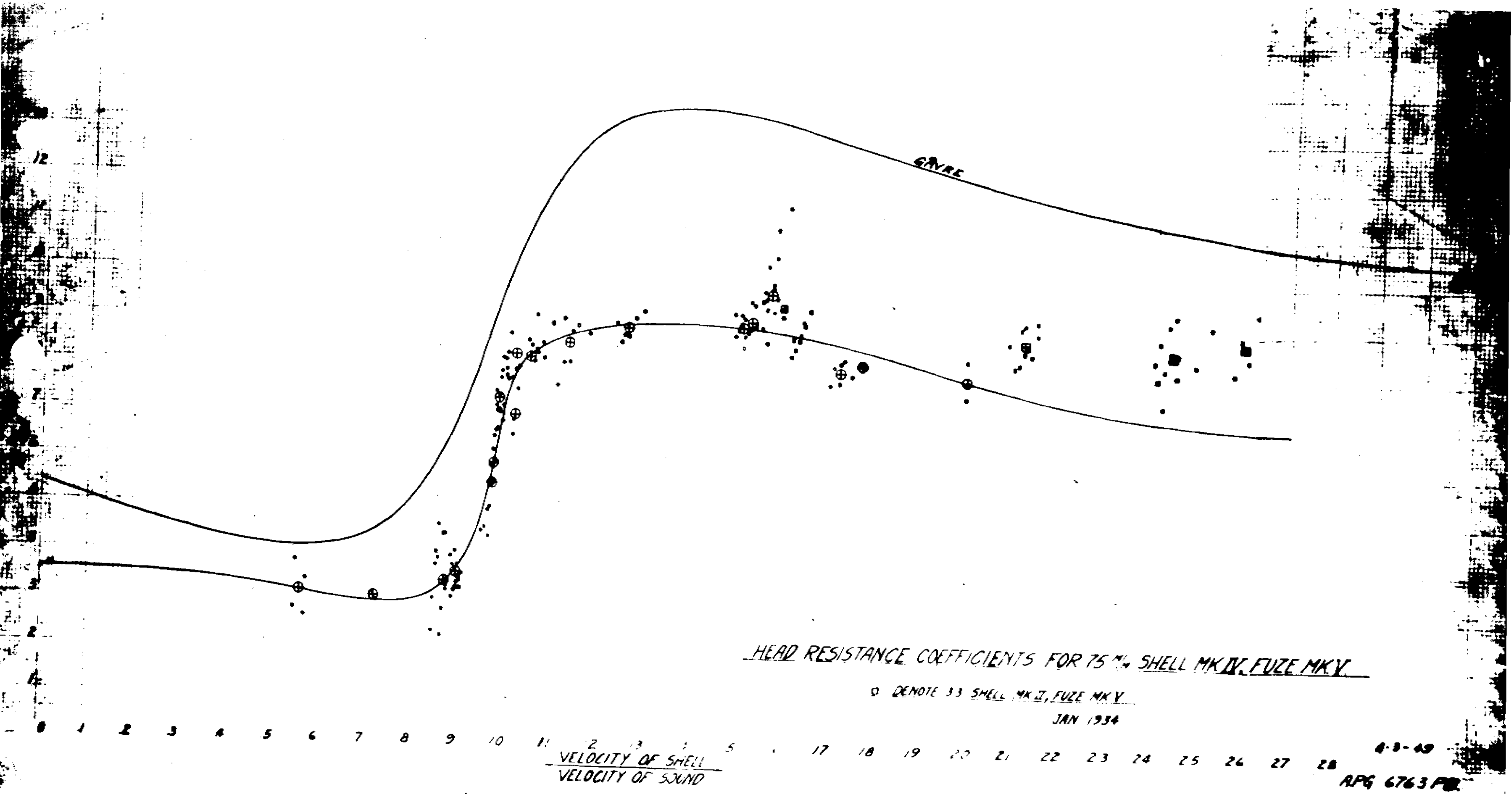
JAN 1934



HEAD RESISTANCE COEFFICIENTS FOR 75 M/M SHELL MK IV, FUZE MK III

△ DENOTES SHELL WITH GROOVE BEHIND ROTATING BAND

G-3-40
A.P.G. 4868-P



HEAD RESISTANCE COEFFICIENTS FOR 75 MM SHELL MK IV, FUZE MK V

□ DENOTE 33 SHELL MK II, FUZE MK V

JAN 1934

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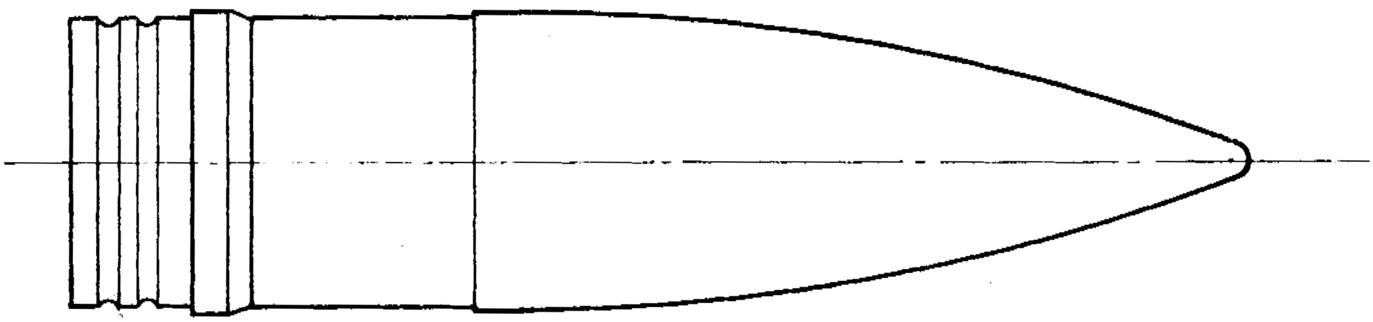
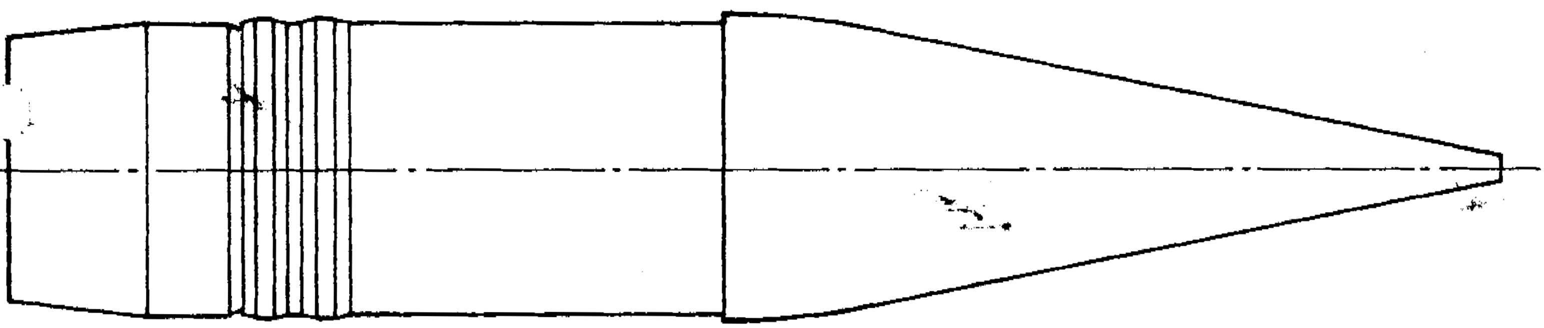
[redacted]

FIG. 3



3" H.E. SHELL, TYPE 1915, FUZE B.D., MK V
RESISTANCE FUNCTION J-6

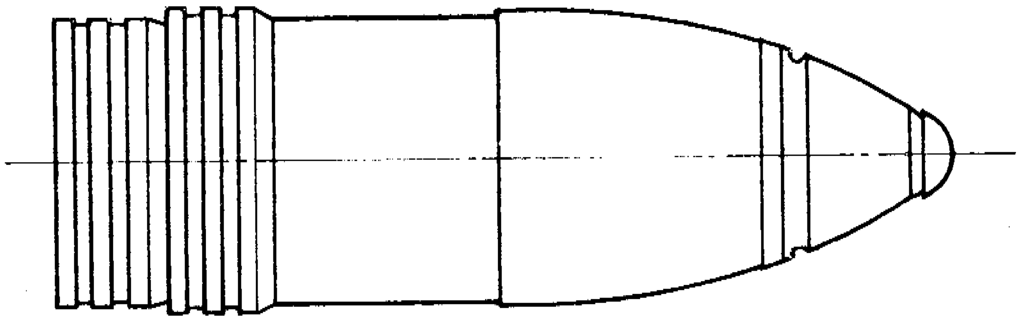


3.3" SHELL, TYPE 155
RESISTANCE FUNCTION J-2

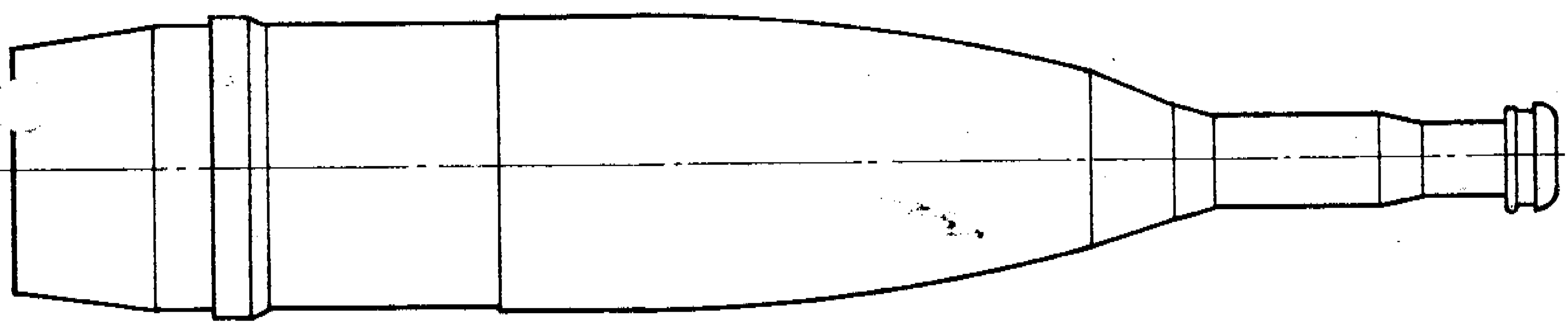
[redacted]

[redacted]

FIG. 4



SHELL, A.A.-3", MK IX - FUZE, MK III
RESISTANCE FUNCTION J-3

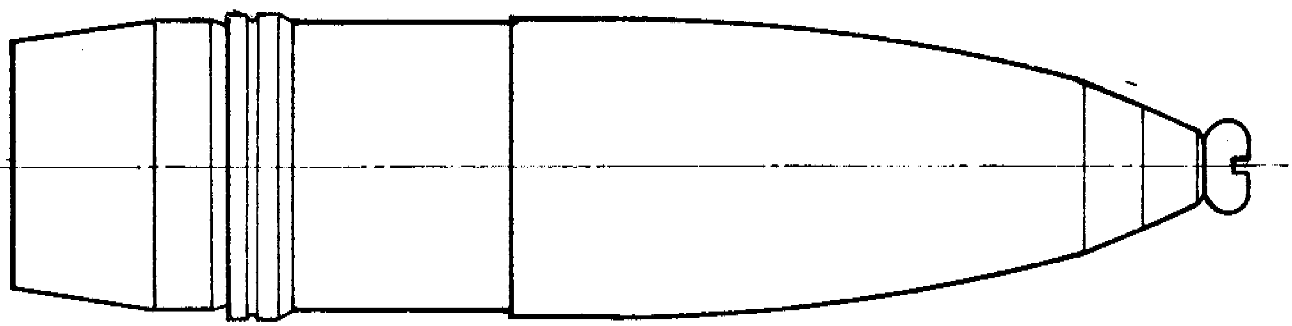


SHELL, H.E.-75 MM, MK IV - FUZE P.D., MK III
RESISTANCE FUNCTION J-4

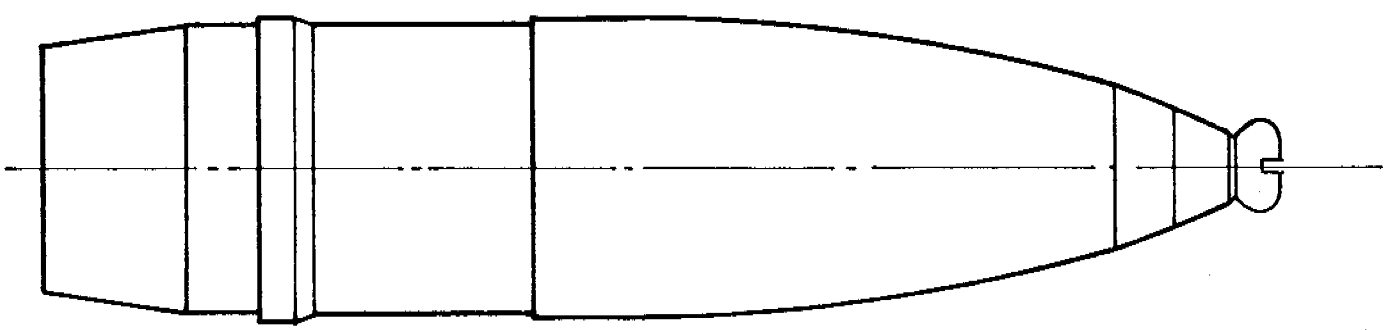
[redacted]D

[redacted]

FIG. 5



3.3" COM.STEEL SHELL MK II, FUZE P.D. MK V
RESISTANCE FUNCTION J-5

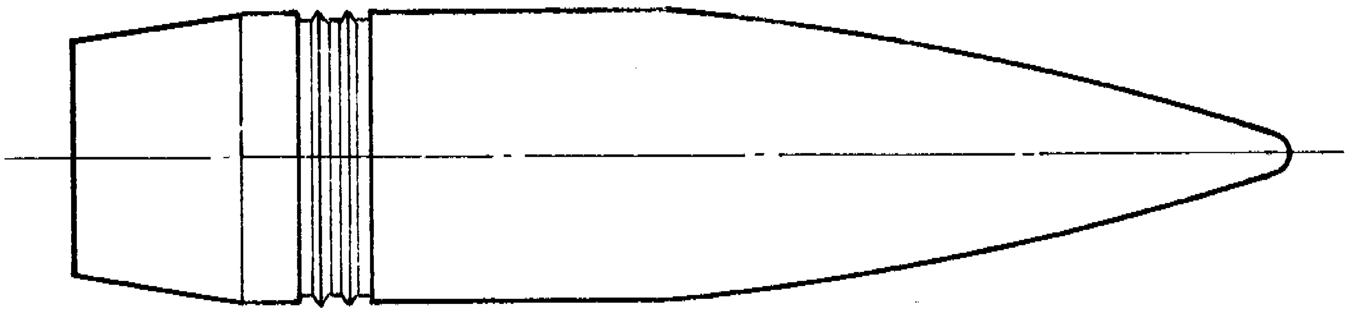


SHELL H.E. - 75 MM MK IV - FUZE, P.D. MK V
RESISTANCE FUNCTION J-5

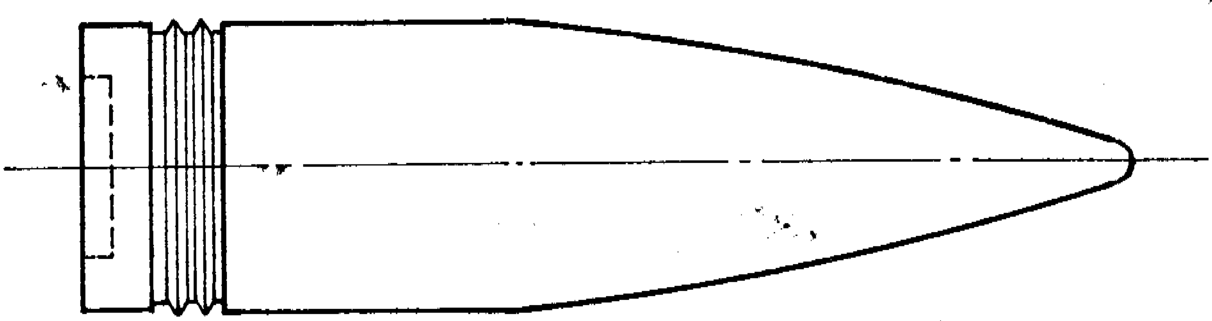
[redacted]

[redacted]

FIG. 6



STANDARD STREAMLINE PROJECTILE
5/10 C.R.H. $7\frac{1}{2}^{\circ}$/0.6 BOAT TAIL
RESISTANCE FUNCTION J-7



STANDARD PROJECTILE
5 10 C.R.H. CYLINDRICAL BASE
RESISTANCE FUNCTION J-8

[redacted]

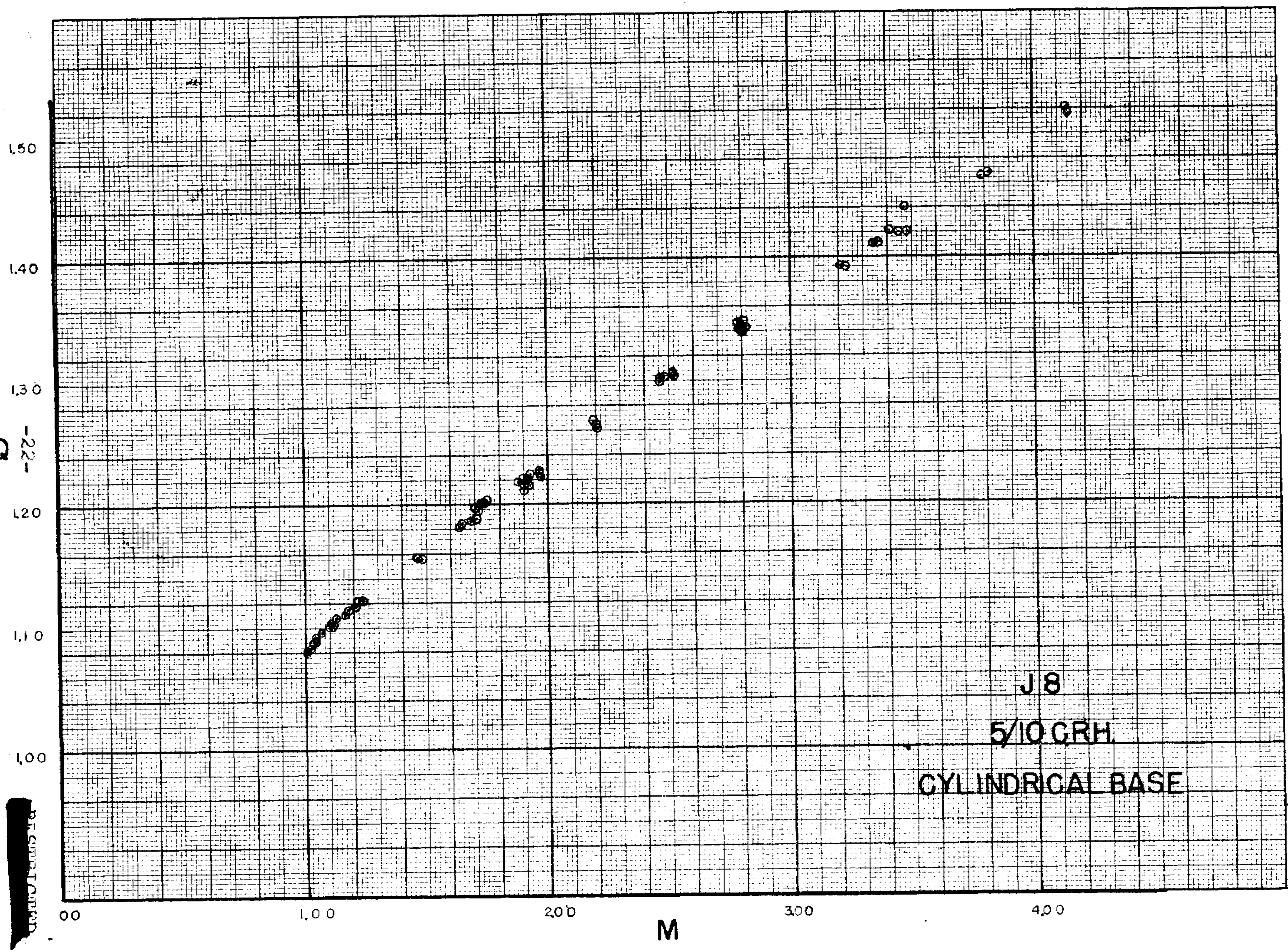


FIG 15 b

[redacted]

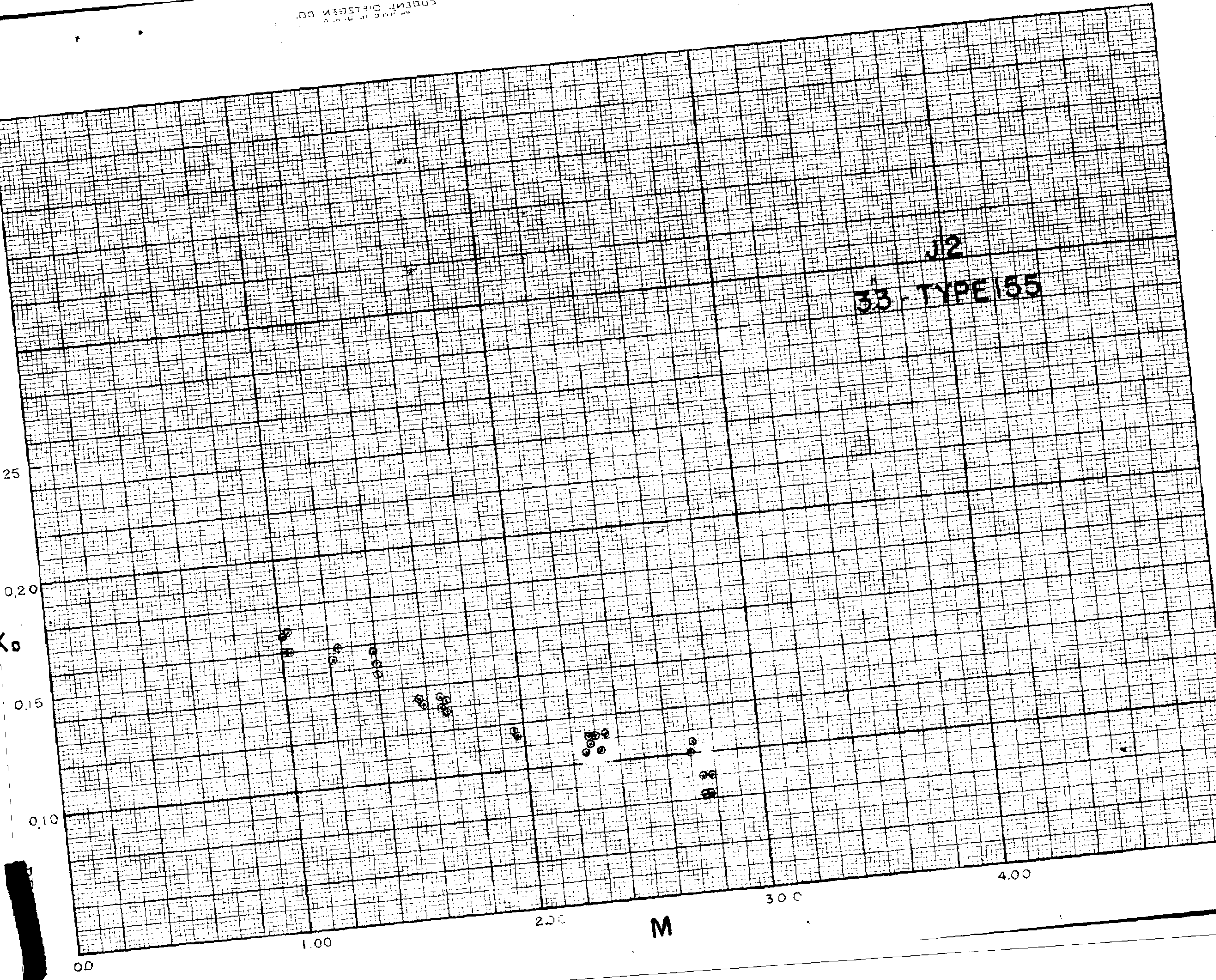
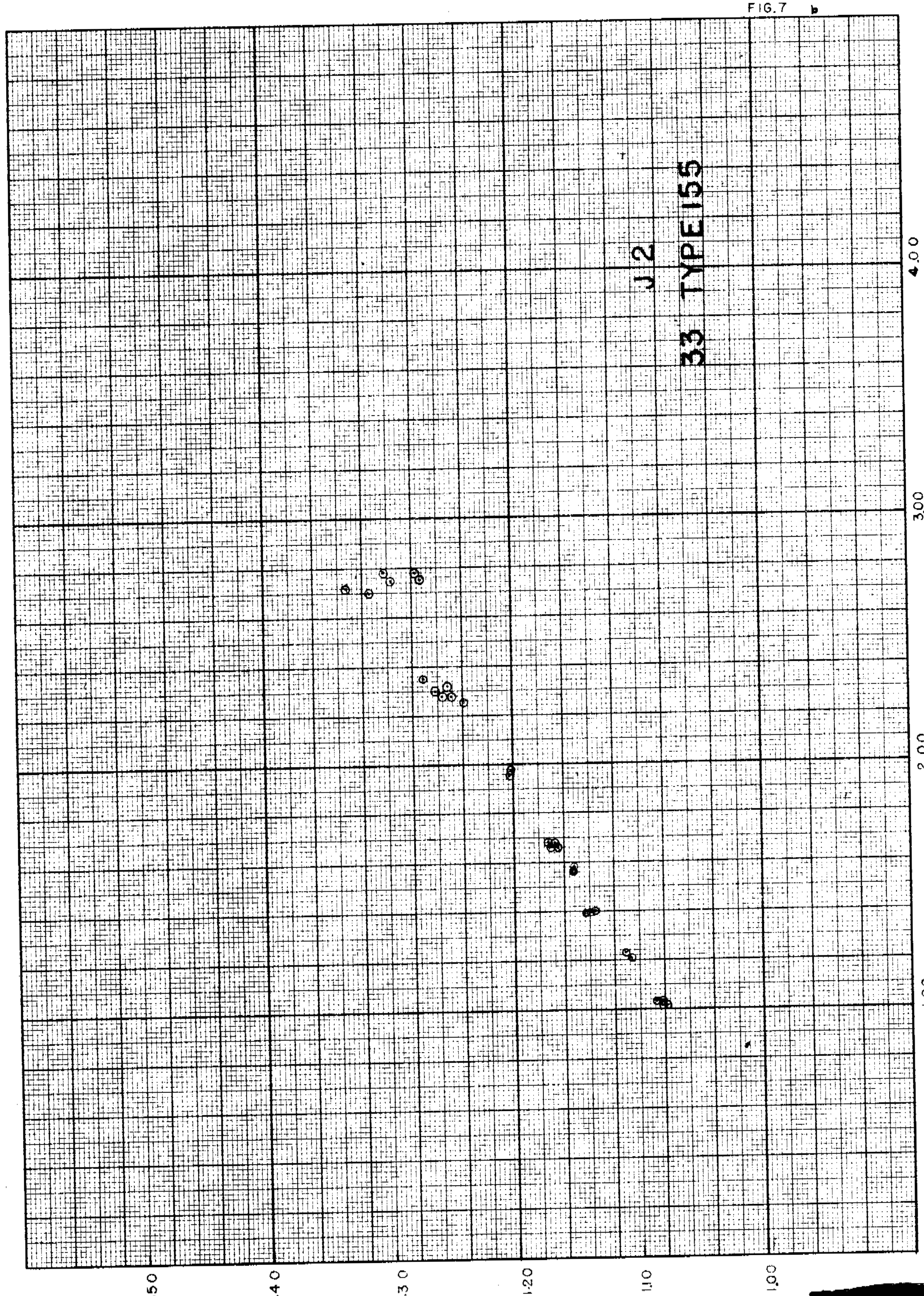


FIG. 7a

[redacted]

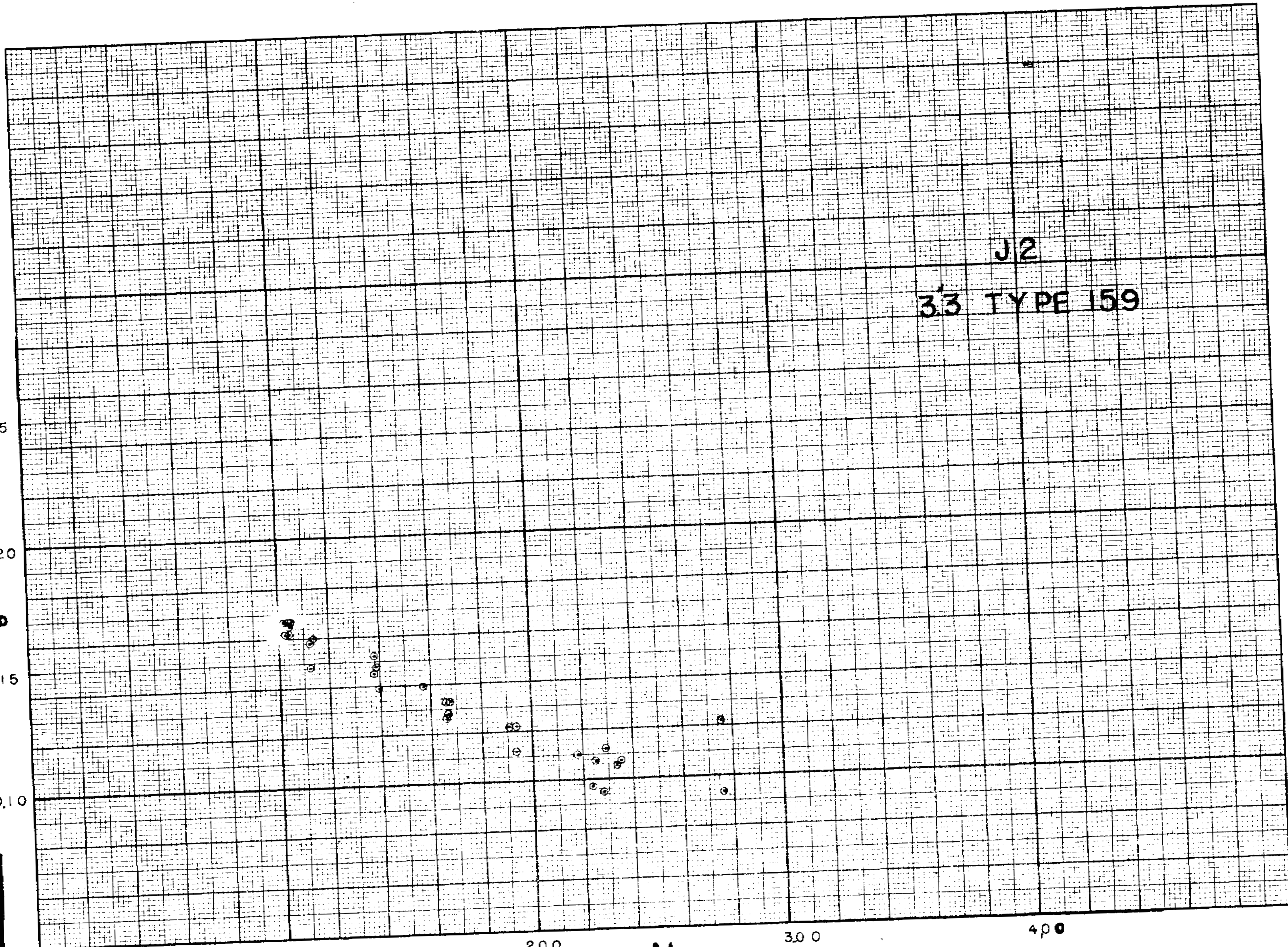
FIG. 7 b



[redacted]

[redacted]

FIG. 8 a



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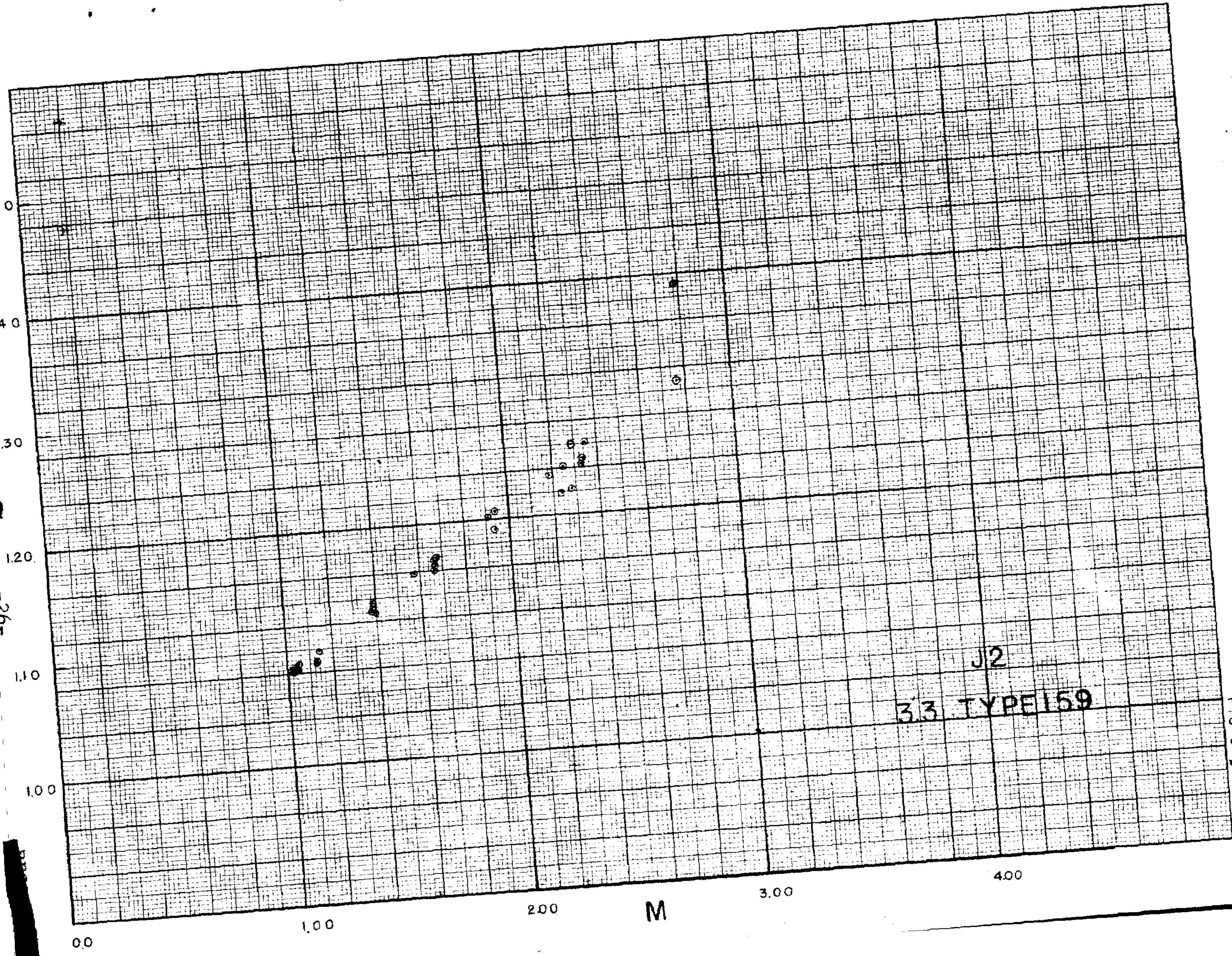
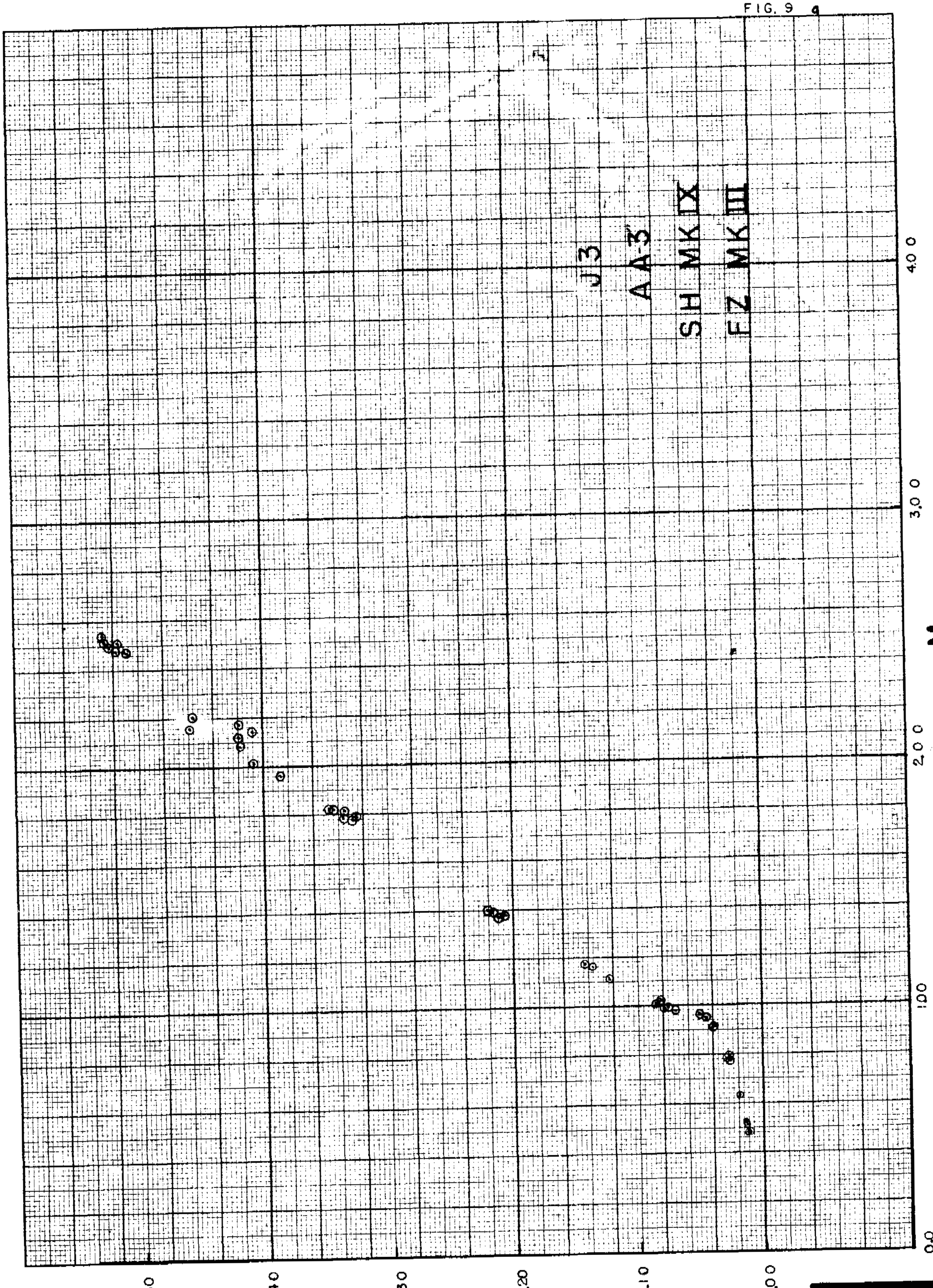


FIG 8 b

FIG. 9



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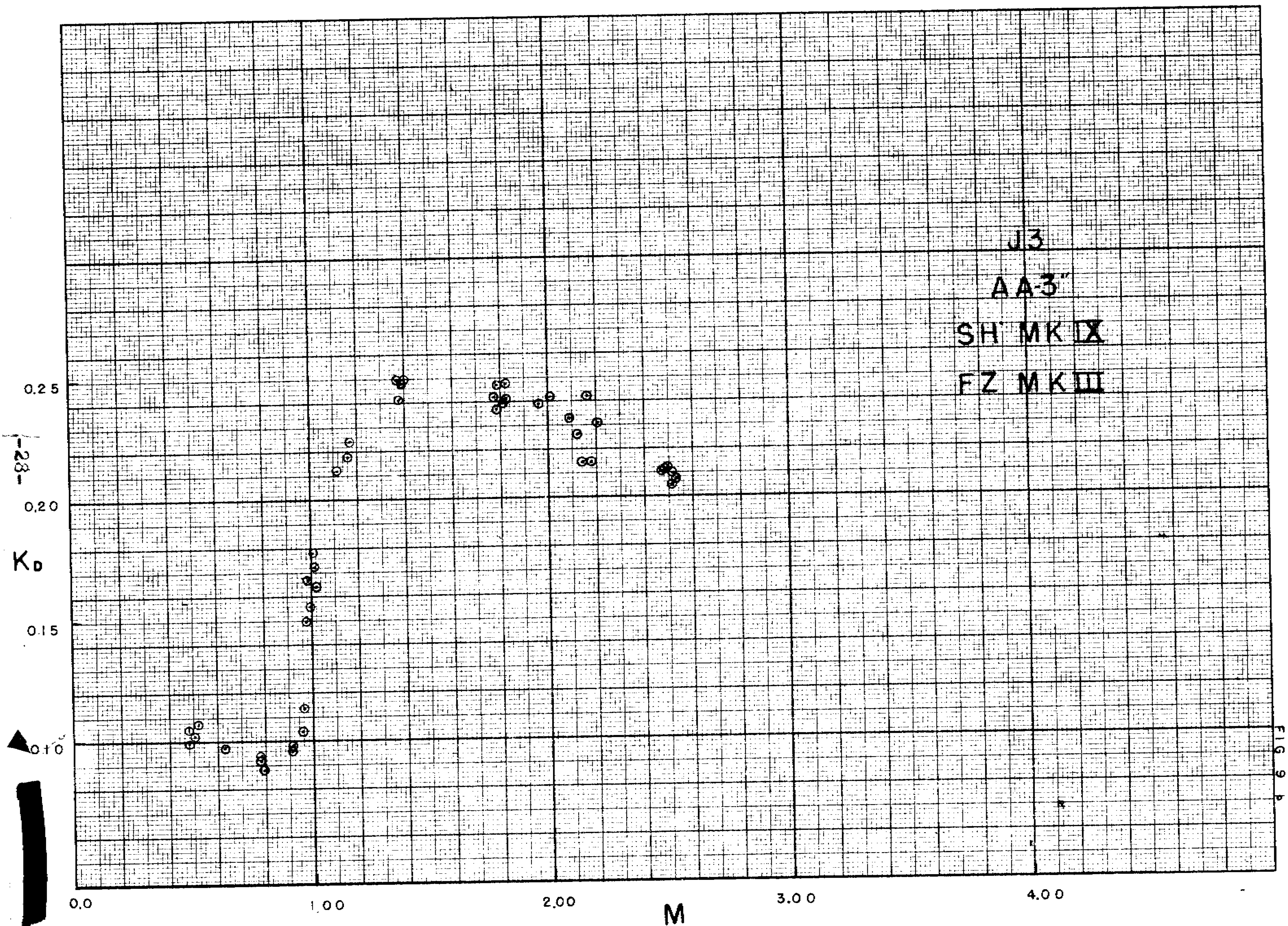


FIG 9 b

[redacted]

[redacted]

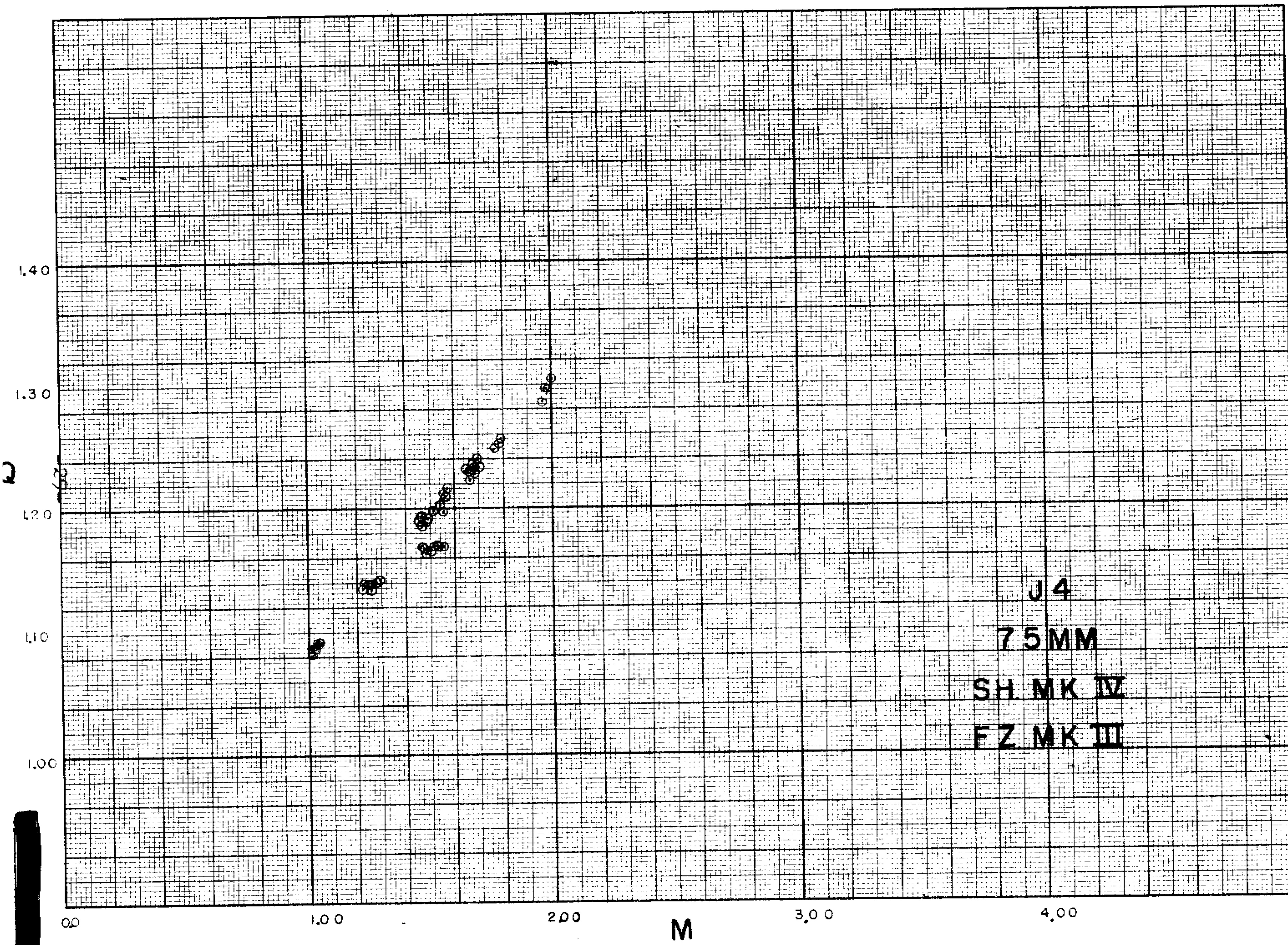


FIG 10 a

[redacted]

[redacted]

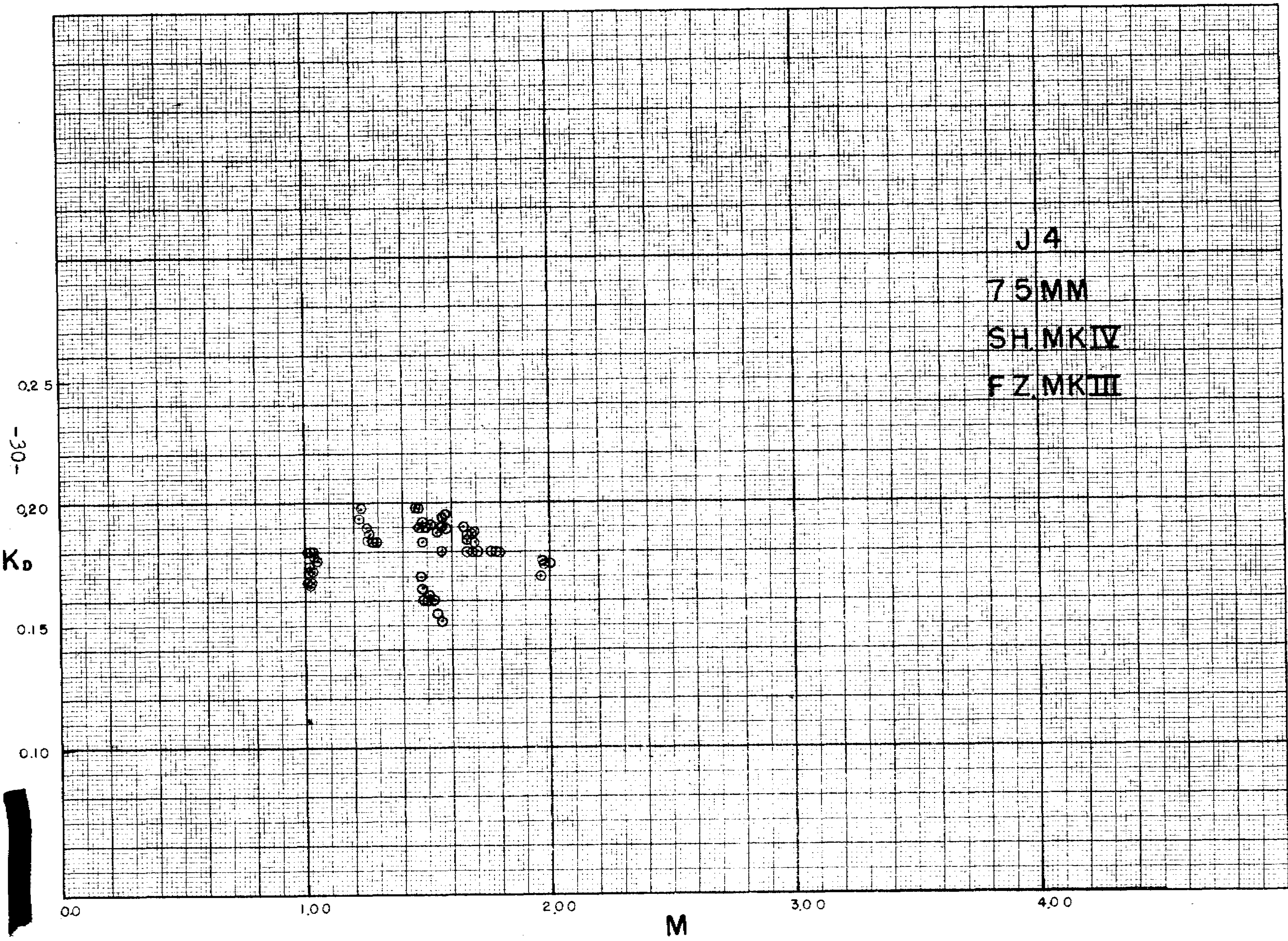


FIG. 10

[redacted]

[redacted]

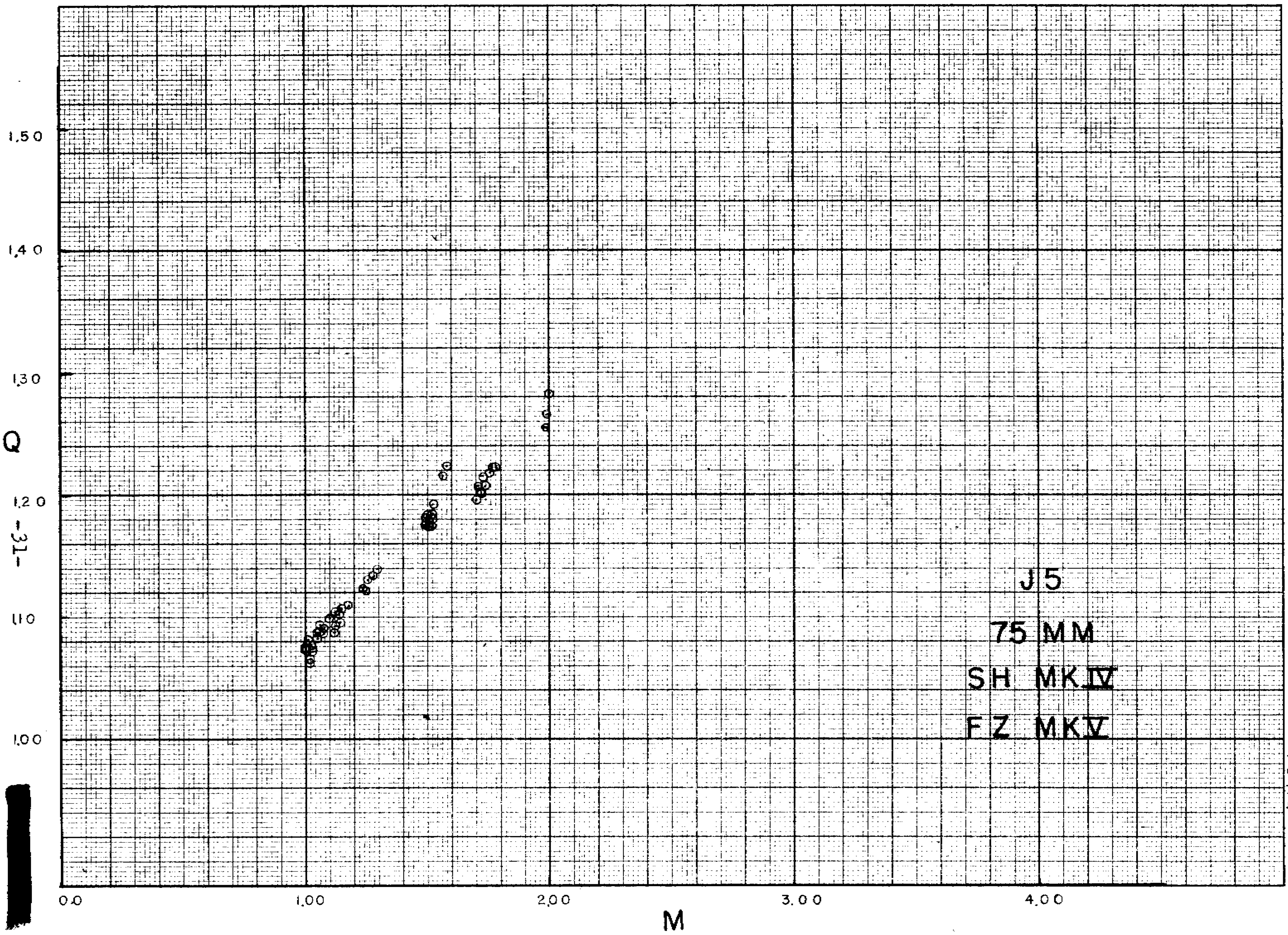


FIG 11a

[redacted]

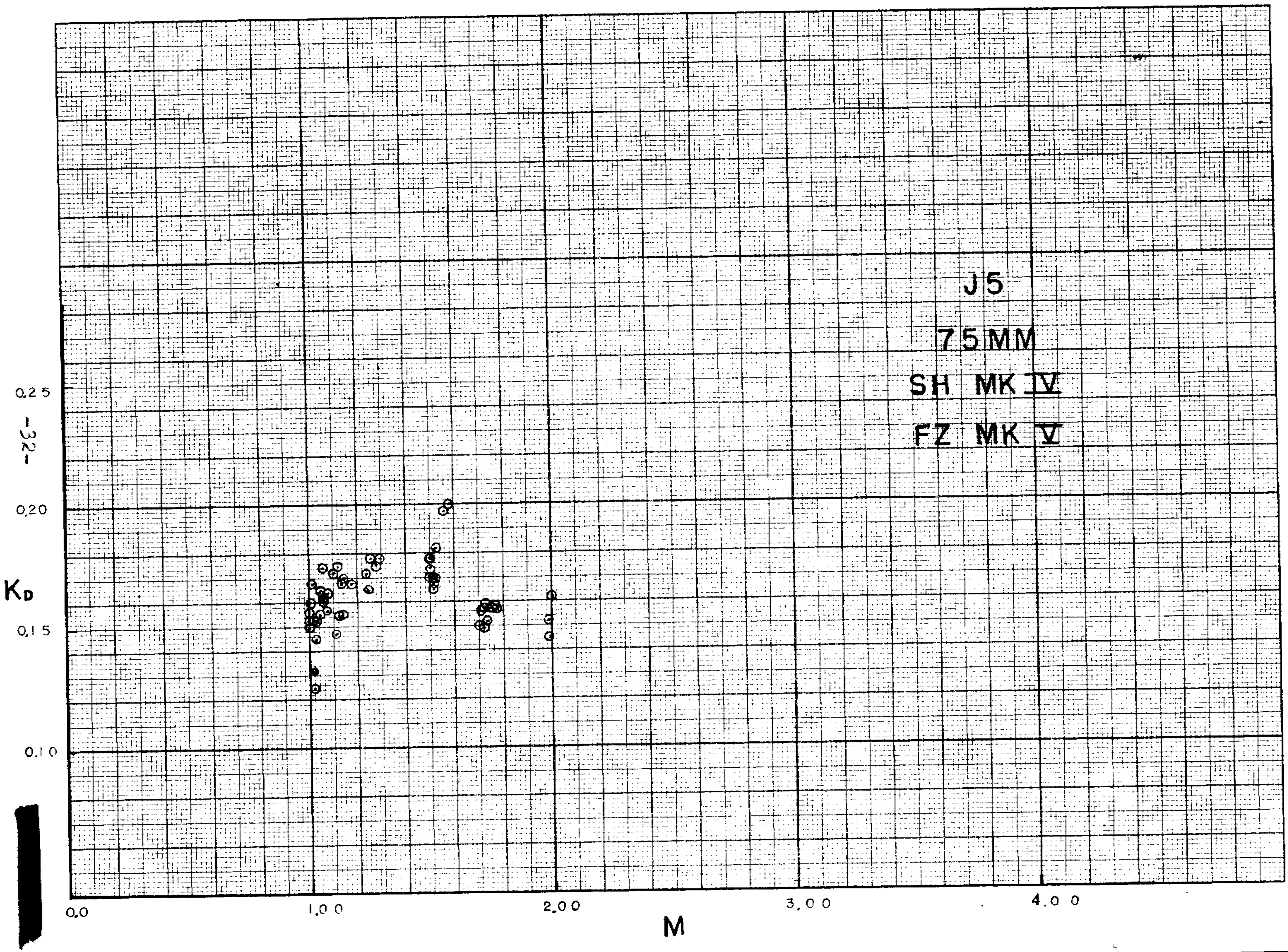


FIG 11b

[redacted]

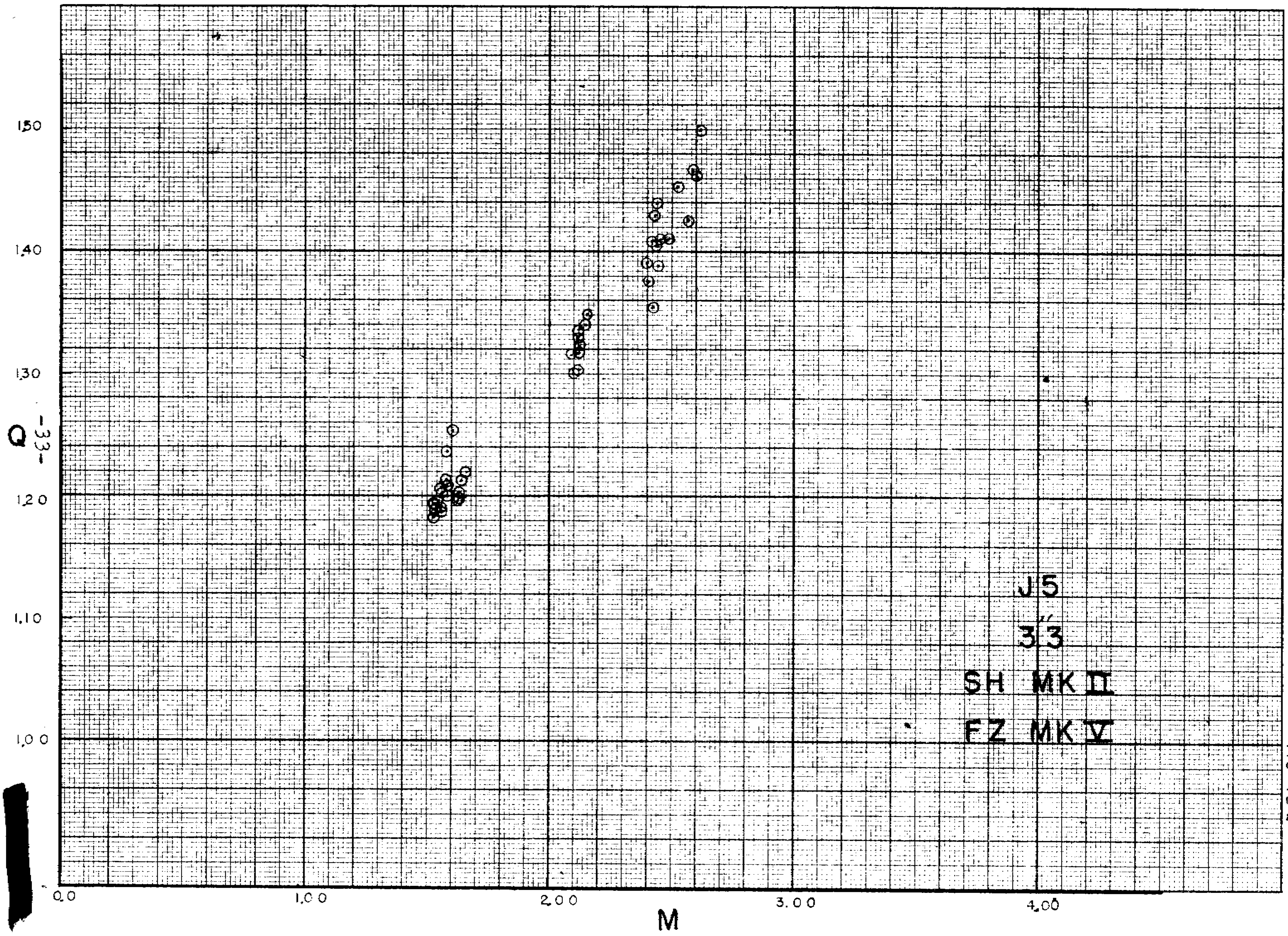


FIG 12.4

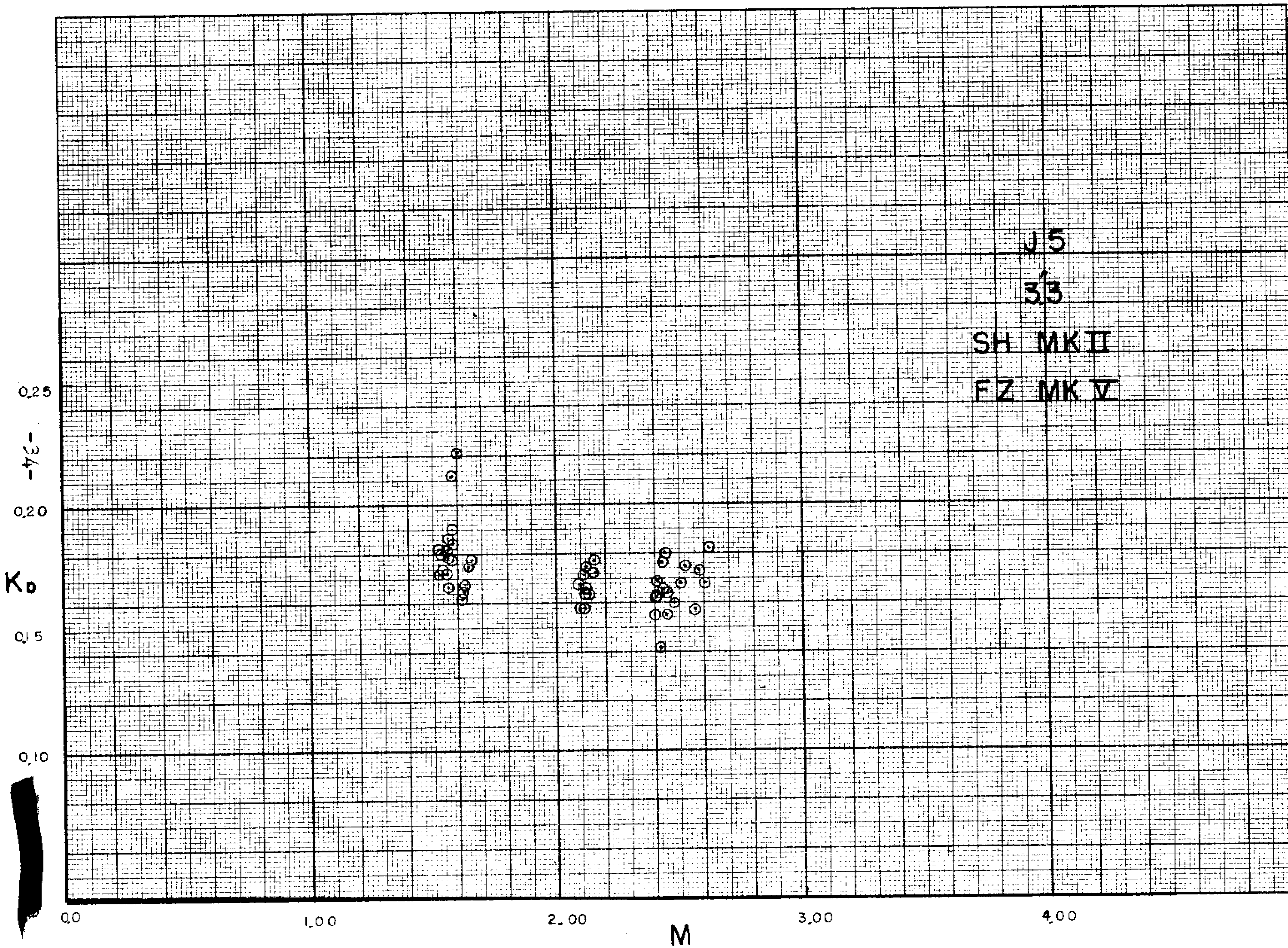
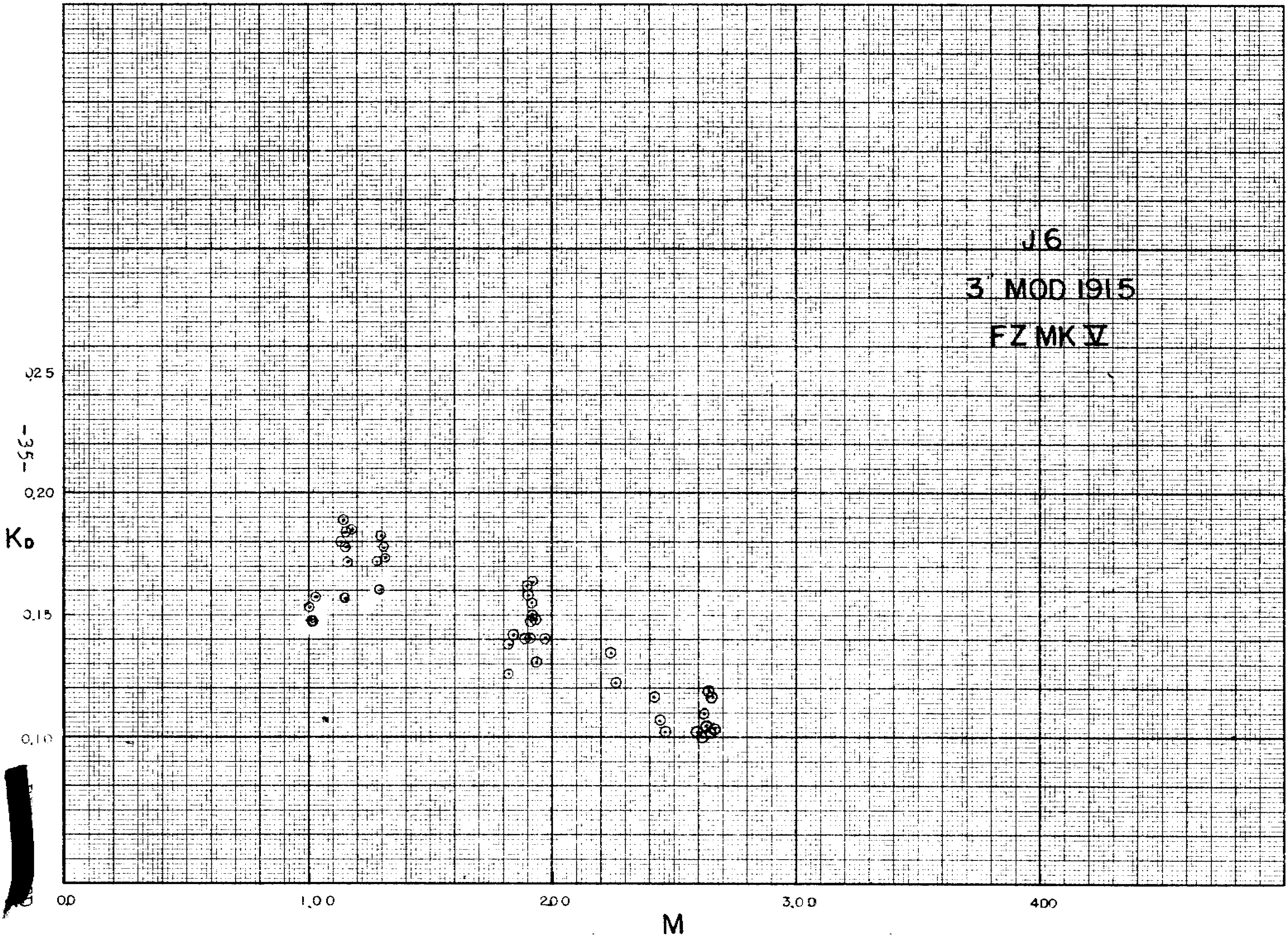


FIG 12 b



[redacted]

FIG. 13a

[redacted]

[redacted]

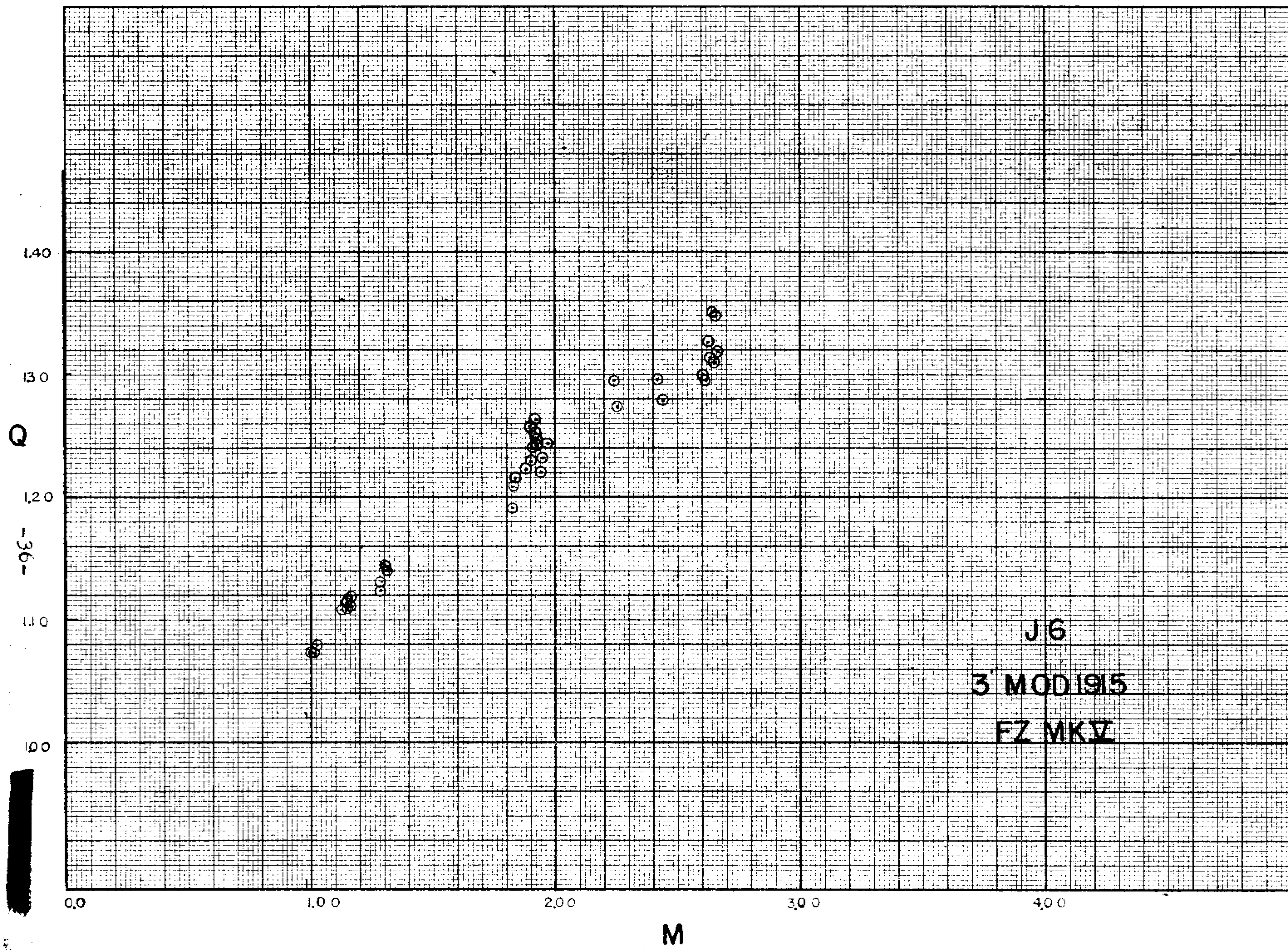


FIG. 13b

[redacted]

[redacted]

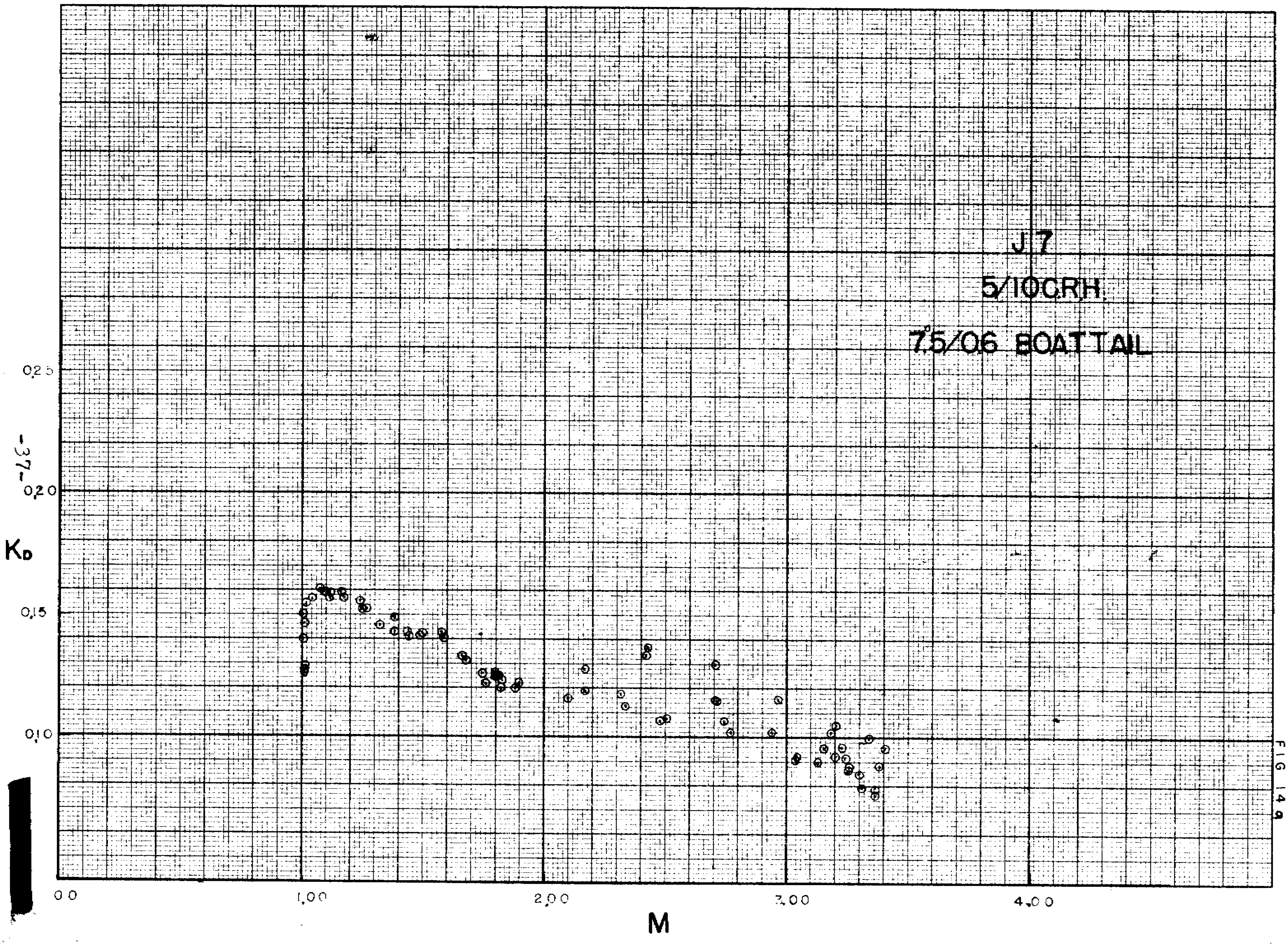
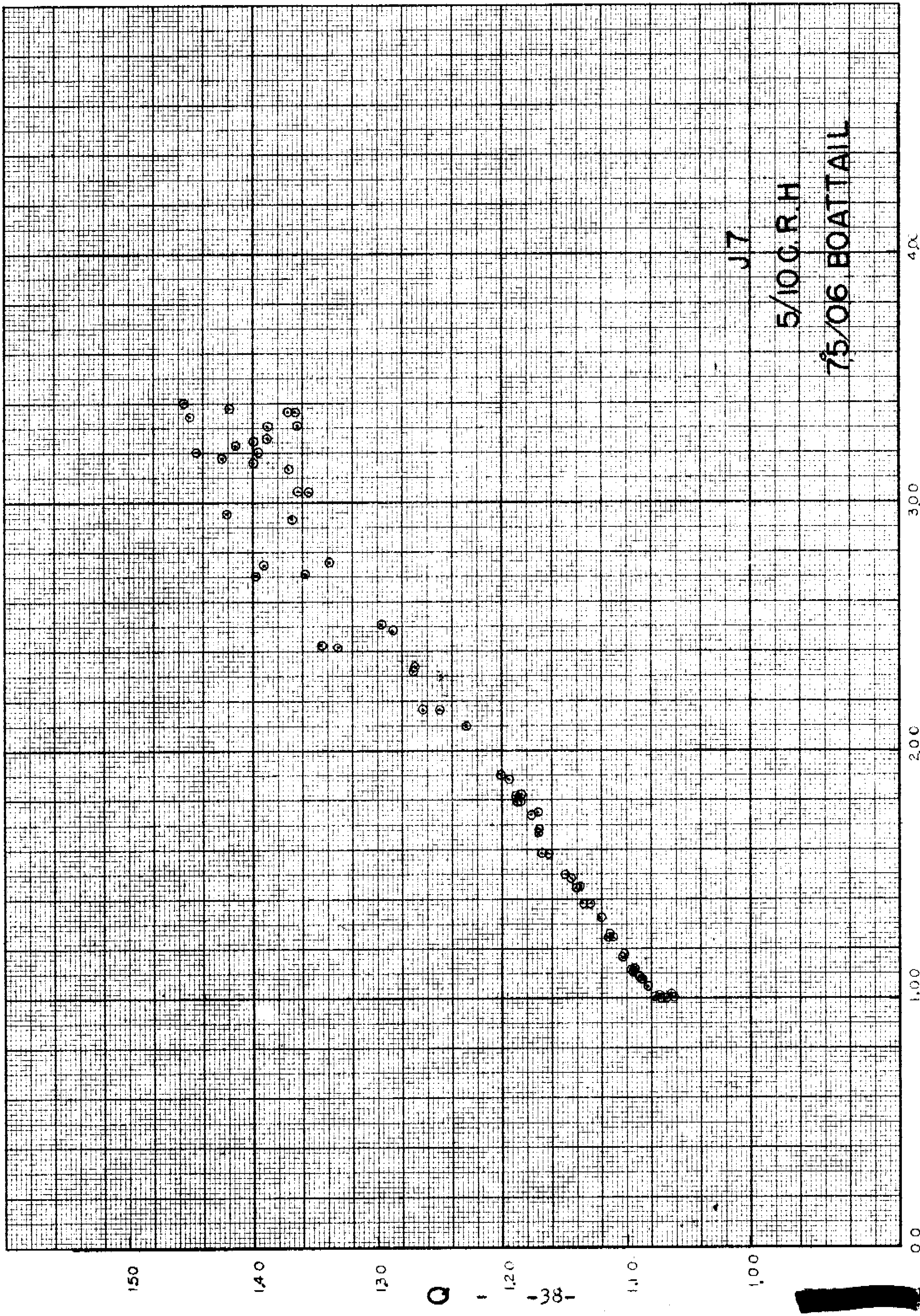


FIG 14 a

[redacted]

[redacted]

FIG 14b



[redacted]

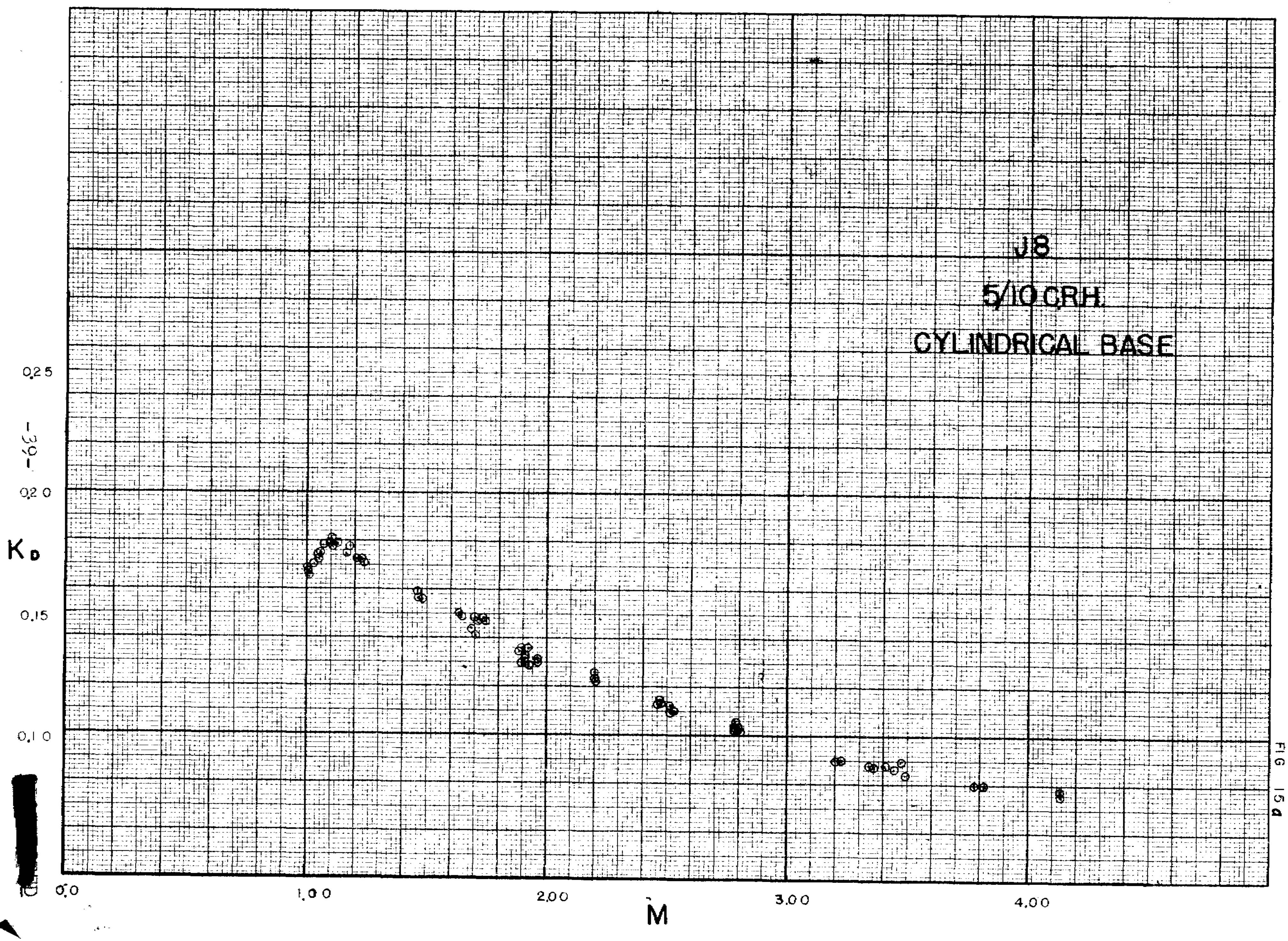
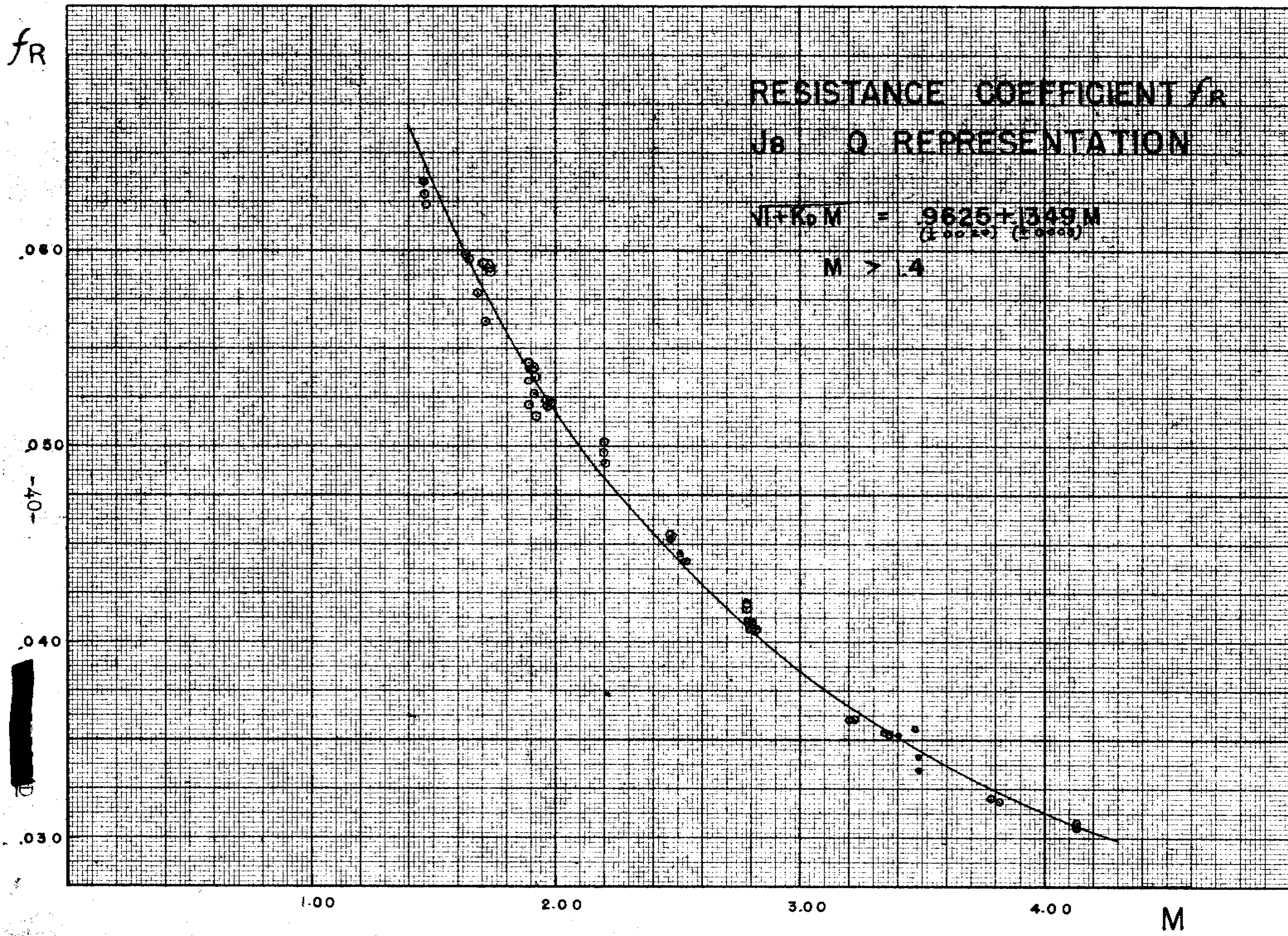


FIG 15 a

[redacted]

[redacted]

FIG. 16



[redacted]

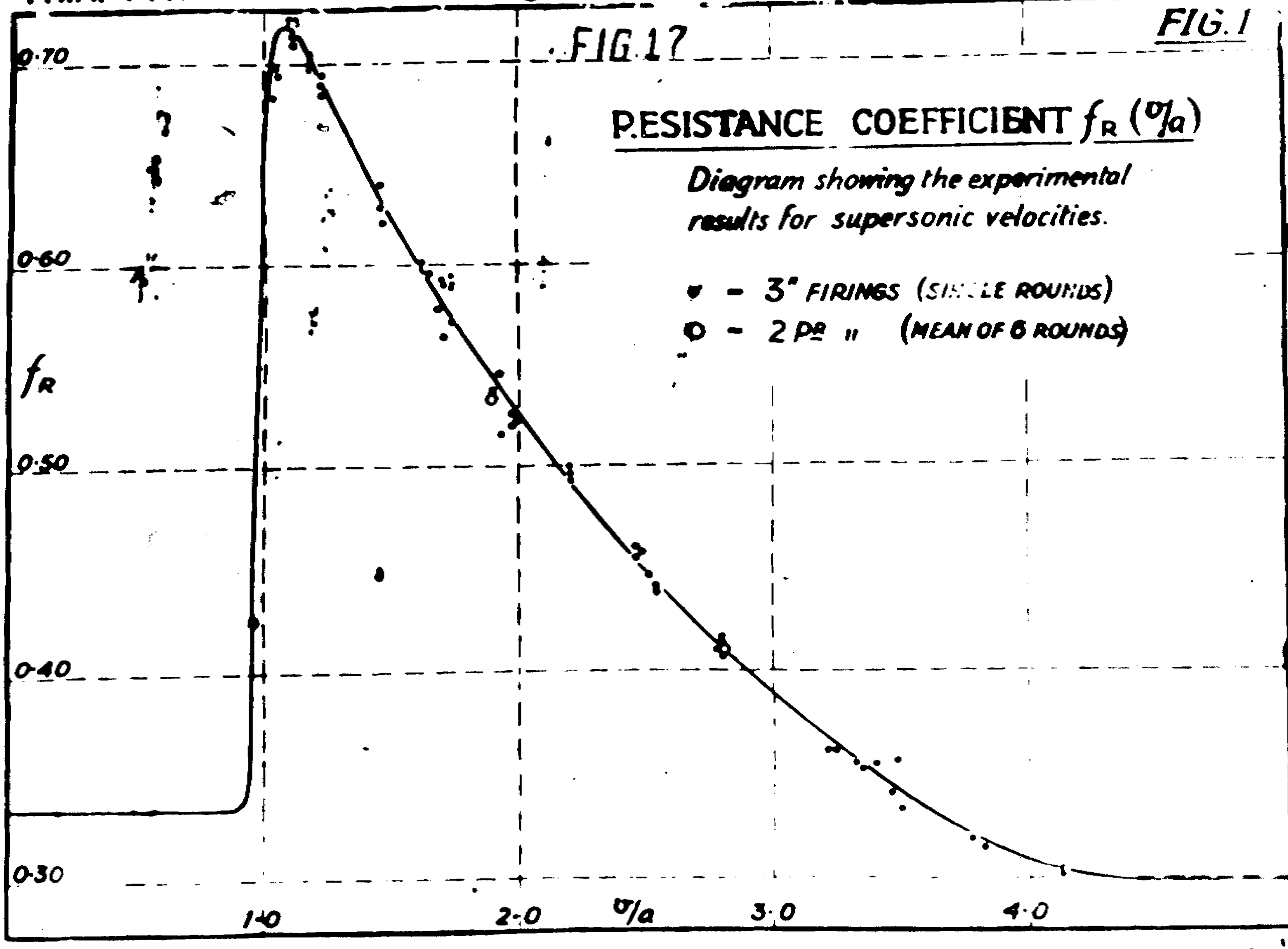
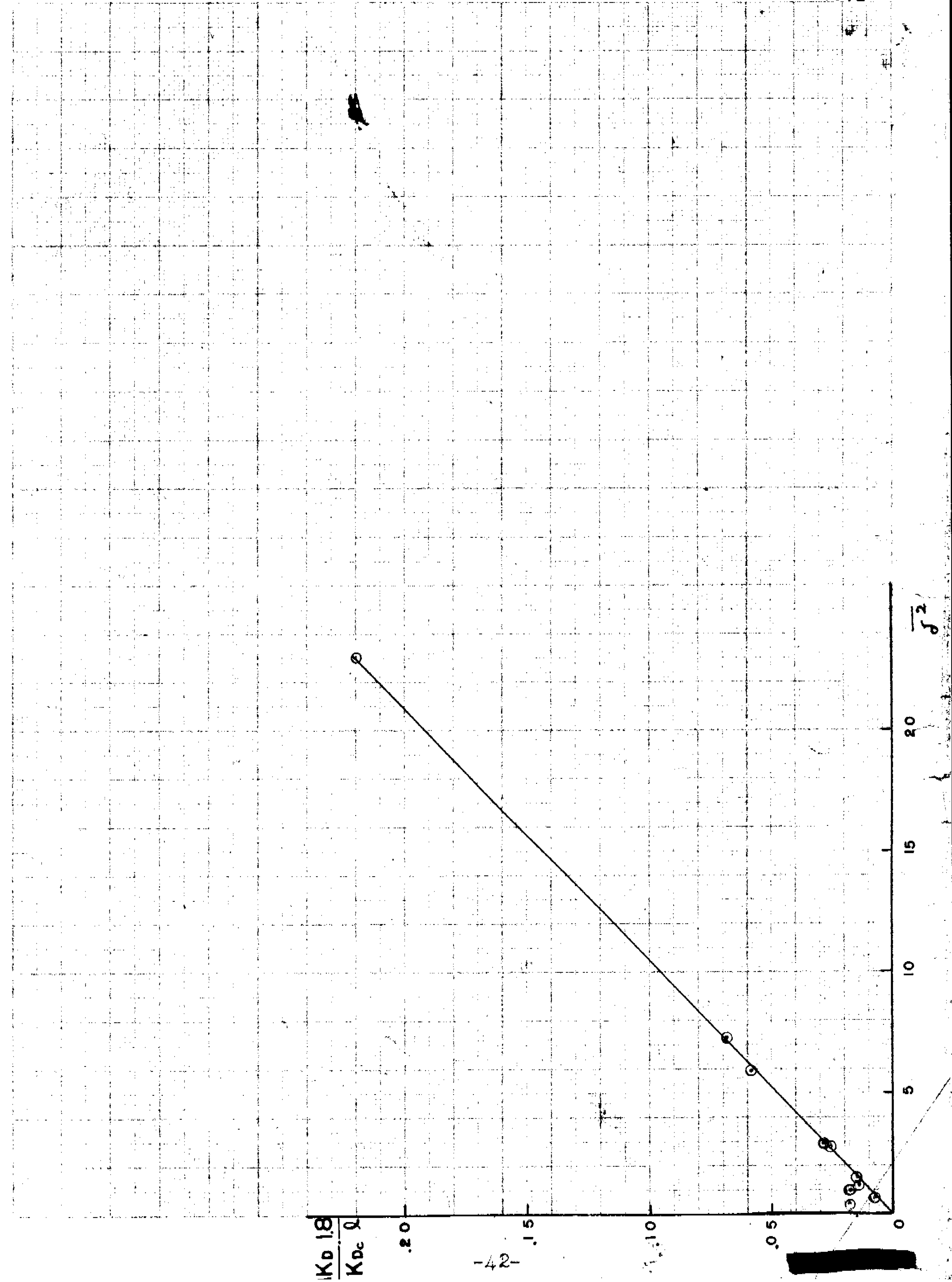


FIG.1
FIG.17
RESISTANCE COEFFICIENT f_R (v/a)
Diagram showing the experimental results for supersonic velocities.
• – 3" FIRINGS (SINGLE ROUNDS)
o – 2 P^R " (MEAN OF 6 ROUNDS)
0·70
0·60
0·50
0·40
0·30
f_R
1·0
2·0
3·0
4·0
v/a
A27878

BRL. 542

[redacted]

FIG. 18



[redacted]

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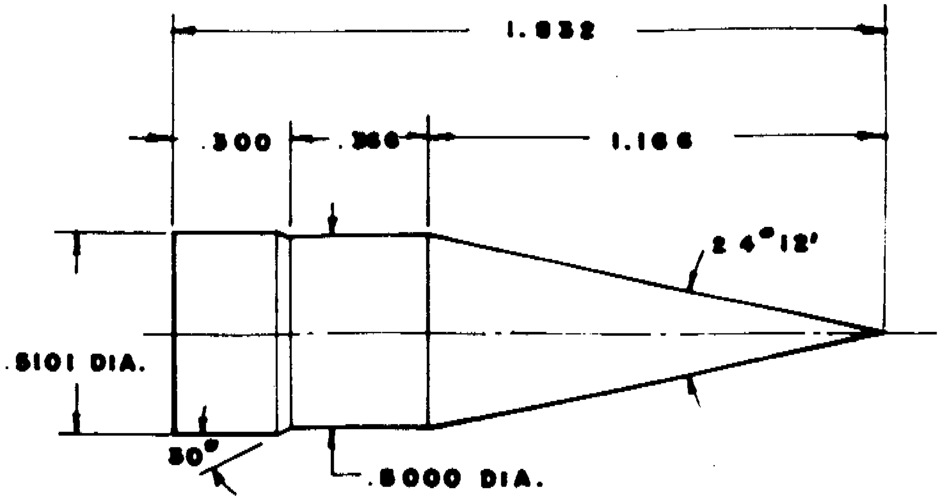
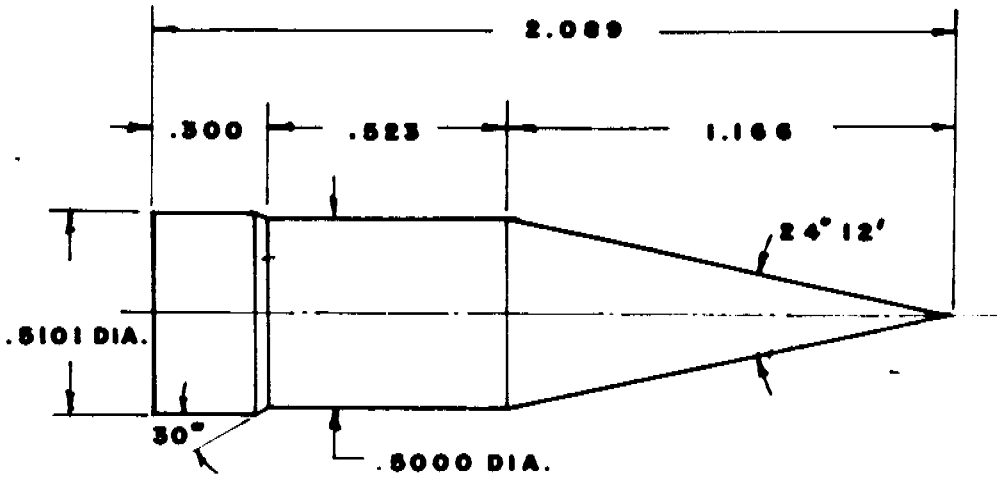


TYPE - A



TYPE - B

[redacted]